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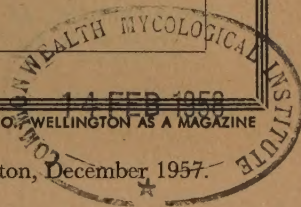
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CORRESPONDENCE.—All communications relative to the Journal should be addressed to the Editor, Department of Scientific and Industrial Research, Wellington.

NOTICE

This is the last issue of the final volume of the *New Zealand Journal of Science and Technology*, which will be replaced in 1958 by three journals:

New Zealand Journal of Agricultural Research,
published in alternate months, first issue February 1958.

New Zealand Journal of Geology and Geophysics,
published quarterly, first issue February 1958.

New Zealand Journal of Science,
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Number 10

RUMEN STUDIES IN SHEEP

IV. THE RUMEN METABOLISM OF FRESH AND DRIED GRASS

By K. R. CHRISTIAN and V. J. WILLIAMS, Ruakura Animal Research Station, Department of Agriculture, Hamilton.

(Received for publication, 15 August 1957)

Summary

Six sheep were fed fresh and dried grass from the same sward at the same level of dry-matter intake, and the concentrations of rumen microbial end-products were determined in samples removed at hourly intervals, two before and six after feeding.

Heat drying of the grass increased the pre-feeding levels of volatile fatty acids but decreased the rise following feeding; changed the large and rapid rise in ammonia after feeding to a continuous fall; lowered the ability of the rumen to support microbial growth; but produced little effect on ruminal protein nitrogen concentrations.

It is concluded that results from rumen fermentation studies using dried grass cannot be applied to grazing animals.

INTRODUCTION

Dried grass is of value in pen-feeding nutritional studies since it provides a natural diet of high quality, which can be fed over long periods with little variability in chemical composition. However, little is known of any change in the end-products of digestion or in their rates of formation resulting from the changes in the grass taking place during drying^{1, 2}. Although it has been shown that heat drying has little effect on the overall digestibility or TDN of grass³, the digestibility of crude protein is reduced⁴. Chalmers *et al.*⁵ have produced evidence that the heating of casein, a readily available protein, can slow down the rate at which ammonia is released in the rumen. Warner⁶ found that heating groundnut meal decreased both the solubility of the protein in 0.05N sodium hydroxide and the total amount of proteolysis by the microflora, although the rate of proteolysis of the soluble protein was unchanged.

It is possible, therefore, that the nature of plant protein is affected by moderate heat to such an extent that rumen metabolism studies on dried grass are not applicable to the grazing animal. A trial has therefore been conducted to study the effect of drying on the concentration of rumen microbial end-products.

EXPERIMENTAL

One acre of a mixed sward consisting mainly of perennial ryegrass, white clover, cocksfoot, and paspalum was divided into 56 equal plots. One alternate plot was mown each day for 28 days (27 September-24 October). The grass was fed fresh and unchopped in two feeds to six mature sheep which were individually penned and had been trained during a 14-day pre-experimental period to eat each feed within an hour.

On every third day, the three corresponding plots were cut and dried in a stream of air at 100–120°C. for 30 minutes. After a settling period of seven days on dried grass, the sheep were fed for 28 days on the experimental dried grass in the same order as that for the fresh and at the same level of dry matter (to within ± 8 g.). Chemical analyses carried out on samples of the feeds dried for 24 hours at 105°C. and the dry-matter intakes on the sampling days are given in Table 1, from which it will be seen that the pasture composition and dry-matter intakes were approximately the same for both the fresh and dried material.

TABLE 1. COMPOSITION OF MORNING FEEDS ON SAMPLING DAYS

	D.M. Fed g.	% D.M.	Chemical Analysis (on d.m. basis)		
			Ash	Crude Protein	Cellulose
Fresh	218	12.8	9.5	22.7	27.6
Dried	222	87.0	10.1	21.0	27.8
Fresh	221	13.0	9.2	21.6	27.4
Dried	226	86.9	9.4	20.0	27.6
Fresh	221	13.0	9.2	17.3	29.7
Dried	214	86.4	9.2	17.3	28.8
Fresh	250	14.8	8.1	17.4	27.4
Dried	258	87.4	8.4	16.4	28.7

Water was available at all times except during the sampling periods.

One day each week rumen samples were removed by stomach tube from all sheep at hourly intervals, two before and six after the morning feed. The animals were then fed their afternoon ration.

The rumen fluid was analyzed for pH, total volatile fatty acids (VFA), free microbial count (FMC), protein nitrogen (PN), and ammonium nitrogen by the methods previously used⁷.

Residual nitrogen (RN) was calculated as the difference between non-protein nitrogen and ammonia. Since ammonia was determined on strained rumen fluid, it is likely that some ammonia was produced through proteolysis by the potassium carbonate. Work has shown that this may amount to 10–20% of the total released. These RN values must, therefore, be considered as lower than the true ammonia-free non-protein nitrogen values.

RESULTS

The concentration curves averaged over all sheep for the various constituents for the separate weeks, representing different stages of maturity of the pasture, are plotted in Figs. 1–6, and the average concentrations are given in Table 2.

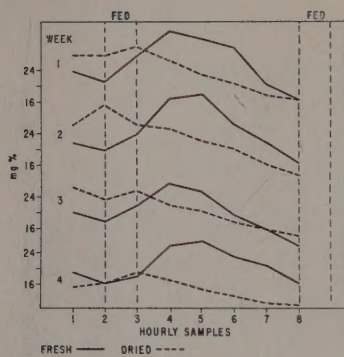


Fig. 1

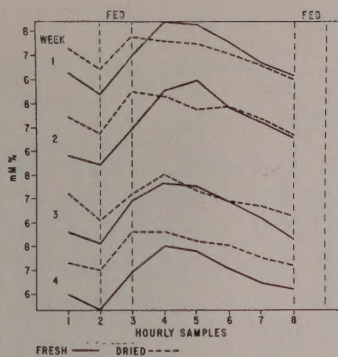


Fig. 2

Fig. 1.—Ammonium nitrogen.

Fig. 2.—Total volatile fatty acid.

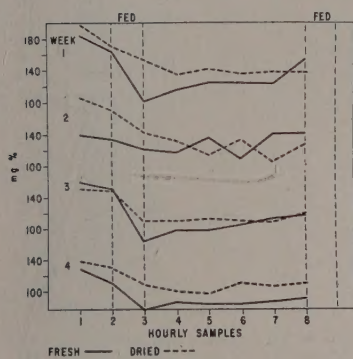


Fig. 3

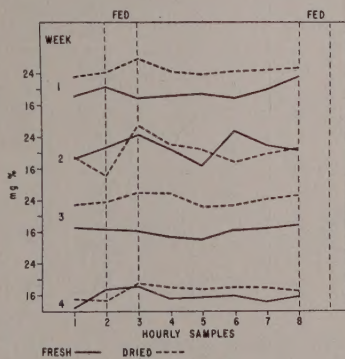


Fig. 4

Fig. 3.—Protein nitrogen.

Fig. 4.—Residual nitrogen.

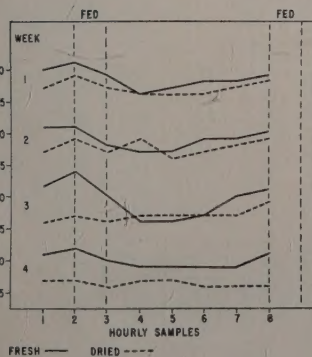


Fig. 5

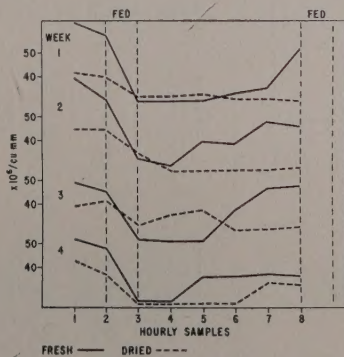


Fig. 6

Fig. 5.—pH.

Fig. 6.—Free microbial count.

TABLE 2. RUMEN ANALYSIS (AVERAGE ALL SHEEP)

Week		1		2		3		4		Average	
Constituent	Sample	Fresh	Dried	Fresh	Dried	Fresh	Dried	Fresh	Dried	Fresh	Dried
Ammonium nitrogen mg. %	1	23.2	27.2	21.0	25.4	19.8	26.0	18.9	15.0	20.7	23.4
	2	20.4	27.0	19.2	30.7	17.3	22.9	15.9	16.0	18.2	24.1
	3	26.8	29.3	23.2	25.6	21.4	25.0	17.6	18.8	22.2	24.6
	4	33.0	25.8	32.2	24.6	26.8	21.4	25.1	16.8	29.2	22.1
	5	31.0	22.1	33.1	21.4	24.7	20.2	26.6	14.4	28.8	19.5
	6	28.7	19.8	25.5	19.5	19.0	17.2	22.6	12.6	23.9	17.2
	7	19.6	17.0	21.0	15.7	15.1	15.2	20.2	11.0	18.9	14.7
	8	15.6	15.6	15.8	12.8	11.2	13.7	15.8	10.4	14.6	13.1
Volatile fatty acids mm. %	1	6.2	7.2	5.8	7.4	5.6	7.2	5.9	7.3	5.8	7.2
	2	5.3	6.3	5.4	6.7	5.1	6.2	5.3	7.0	5.2	6.5
	3	6.9	7.7	6.9	8.4	6.9	7.2	6.9	8.6	6.9	7.9
	4	8.3	7.5	8.5	8.2	7.6	8.0	8.0	8.6	8.1	8.0
	5	8.2	7.4	3.9	7.7	7.5	7.4	7.8	8.2	8.1	7.6
	6	7.5	7.0	7.8	7.8	6.9	6.9	7.4	8.0	7.4	7.4
	7	6.6	6.5	7.2	7.2	6.2	6.7	6.8	7.5	6.7	6.9
	8	6.1	5.9	6.6	6.6	5.3	6.4	6.2	7.2	6.0	6.5
Protein nitrogen mg. %	1	182	196	139	185	159	151	130	139	152	167
	2	162	169	133	169	150	148	112	132	139	154
	3	100	151	120	141	85	110	79	110	96	128
	4	114	134	116	130	98	110	88	102	104	119
	5	123	140	135	113	98	112	86	99	110	116
	6	123	134	109	132	104	110	86	112	105	122
	7	121	136	139	105	112	110	89	108	115	114
	8	152	136	140	126	118	119	93	112	125	123
Free microbial count (x10 /cu.mm)	1	62	41	66	44	49	39	52	43	57	41
	2	57	39	56	44	45	41	48	37	51	40
	3	29	31	32	34	25	31	26	25	28	30
	4	29	31	29	27	24	35	26	25	28	29
	5	29	32	39	27	24	37	36	25	27	30
	6	32	30	38	27	37	29	36	25	35	27
	7	34	30	47	27	46	29	37	33	41	29
	8	50	29	45	28	47	30	36	32	44	29
Residual nitrogen mg. %	1	17.8	22.7	18.3	18.6	17.0	22.8	12.6	15.1	16.4	19.8
	2	20.2	23.7	21.1	14.0	16.6	23.5	17.2	14.9	17.0	19.0
	3	17.3	27.2	24.4	26.8	16.3	25.8	18.3	18.9	19.0	24.6
	4	17.7	24.1	20.9	22.2	14.8	25.6	15.4	17.8	17.2	22.4
	5	18.5	23.2	16.6	20.6	14.1	22.4	15.6	17.5	16.2	20.9
	6	17.8	24.0	25.3	17.7	16.3	22.6	15.9	17.9	18.8	20.5
	7	19.4	24.2	21.6	19.7	16.7	24.2	14.3	17.9	18.0	21.5
	8	22.7	24.9	20.6	20.8	17.6	25.0	15.6	17.0	19.1	21.9
pH	1	7.0	6.7	7.1	6.7	7.2	6.6	7.1	6.7	7.1	6.6
	2	7.1	6.9	7.1	6.9	7.4	6.7	7.2	6.7	7.2	6.8
	3	6.9	6.7	6.8	6.7	7.0	6.6	7.0	6.6	6.8	6.6
	4	6.6	6.6	6.7	6.9	6.6	6.7	6.9	6.7	6.7	6.7
	5	6.7	6.6	6.7	6.6	6.6	6.7	6.9	6.7	6.7	6.6
	6	6.8	6.6	6.9	6.7	6.7	6.7	6.9	6.6	6.8	6.6
	7	6.8	6.7	6.9	6.8	7.0	6.7	6.9	6.6	6.9	6.7
	8	6.9	6.8	7.0	6.9	7.1	6.9	7.1	6.6	7.0	6.8

TABLE 3. STATISTICAL ANALYSIS OF INDIVIDUAL SAMPLING TIMES

Constituent	Component	D.F.	Sampling Times							
			1	2	3	4	5	6	7	8
Ammonium nitrogen	Feed	1	59.4	427.8	61.2**	600.7**	1041.6**	406.0*	218.4	25.7
	Sheep	5	47.4*	51.7**	37.1	9.0	27.1	51.6**	46.0**	43.3
	SxW	5	22.0	13.5	12.3	7.0	11.5	15.0	15.4	11.8
	Weeks	3	148.6	195.0	219.6**	185.4**	123.9	88.2	37.2	20.8
	FxW	3	50.4*	66.4**	6.1	4.4	38.0*	33.2*	47.6**	35.3**
	SxW	15	4.9	10.1	10.8	4.5	8.9	8.8	5.2	5.0
FxSxW	15	10.6	10.3	6.0	5.2	8.6	7.0	6.8	3.4	
Volatile fatty acids	Feed	1	23.80*	21.46**	21.74*	0.00	2.52	0.10	0.36	2.53
	Sheep	5	5.71	6.03	2.23	2.17	3.54	3.77	4.39	4.61
	SxW	5	2.66**	2.43**	2.53**	1.86**	2.45**	1.99**	3.16**	2.37**
	Weeks	3	0.12	0.51	0.46	0.87	1.54	1.38	1.42	2.17
	FxW	3	0.26	0.53	0.56	1.27	1.49	1.04	0.72	1.32
	SxW	15	0.60	0.36	0.60*	0.58	0.60	0.64	0.32	0.43
FxSxW	15	0.38	0.19	0.26	0.39	0.48	0.38	0.28	0.43	
Protein nitrogen	Feed	1	2745*	2977*	16099**	2700	374	3104	2	94
	Sheep	5	11051**	6602**	4975**	3400**	4075**	3780**	4329**	5173**
	SxW	5	456	517	1039	1266	520	1262	740	421
	Weeks	3	6042	3961**	2951*	2425*	3557**	2057*	2000	3890**
	FxW	3	1541	795	375	37	1125	277	1766	758
	SxW	15	880	1113	591	439	306	240	468	344
FxSxW	15	470	505	901	998	404	767	371	382	
Residual nitrogen	Feed	1	135.3	0.8	374.6**	324.5	268.4**	33.7	148.4	93.8
	Sheep	5	61.1	36.4*	53.0	67.8**	39.3*	56.3	25.4	90.0
	SxW	5	49.9*	16.0	49.5*	8.2	15.2	60.4	20.2	17.1
	Weeks	3	105.2**	81.8	102.3	57.9	27.1	50.0	75.4	117.2
	FxW	3	18.0	114.8**	67.8*	55.6*	21.3	127.6*	47.2	30.2*
	SxW	15	7.7	9.4	10.9	9.2	20.8	15.3	21.9	12.2
FxSxW	15	15.0	13.6	12.7	8.7	9.1	27.4	13.2	9.0	

* P<0.05,

** P<0.01

An overall analysis of the data for ammonia, RN, VFA, and PN, reveals the presence of significant feed interactions with the other factors, and analysis for the separate weeks has been undertaken to assist in interpretation.

Although there is no significant difference in any week between the two feeds averaged over the day, the interactions with time and sheep are invariably highly significant and it appears that the shapes of the fermentation curves for the two feeds are different and that the sheep have not reacted consistently to the drying of the grass.

Statistical analysis of the results at separate sampling times (Table 3) shows important effects of drying on the pre-feeding concentrations of VFA and PN, on all constituents for the first sample after feeding, and on ammonia for the three succeeding samples. Large differences exist between sheep for the individual feeds, except in ammonia levels on dried grass, suggesting that the attack on the nitrogenous constituents is more uniform with dried grass. The sheep show marked individual reactions in VFA levels towards the drying of grass.

When fresh and dried grass are considered separately, significant differences are found between weeks in ammonia and PN, but not in VFA. The significant interaction of feeds with weeks for ammonia at most sampling times indicates that the drying process has different effects depending on the stage of growth.

No analysis of variance has been made on FMC, as determinations were carried out on samples bulked over all sheep. Fig. 6 indicates that bacterial concentrations are higher for fresh than dried grass prior to feeding and at the end of the sampling period.

DISCUSSION

Considerable changes in the concentration curves were brought about by drying, although there were no overall significant differences between the two feeds. It is clear that sampling at random times or at one or two fixed times in relation to feeding could lead to erroneous conclusions.

The ammonia curves for the fresh grass were marked by a large rise immediately after feeding as a result of the rapid fermentation of the nitrogenous feed constituents. Apparently the energy status of the microflora prior to feeding grass was low⁸ and the attack on plant protein to obtain energy resulted in a production of ammonia far in excess of their requirements. The subsequent fall to concentrations lower than those before feeding was most likely due not only to absorption but also to rapid depletion of readily available plant nitrogen and increased utilization of ammonia by the microflora as a result of their greater metabolic demands. The rise after feeding was small compared with that on some artificial diets⁹, which could have been caused by the lower availability of the protein, a more balanced relationship between available energy and protein, or both.

The pre-feeding ammonia concentrations were not significantly different between the two feeds, but the steady fall after feeding dried grass, in contrast to the rise on fresh grass, indicates that drying lowered the susceptibility of the feed nitrogen to bacterial attack. Furthermore, the higher pre-feeding VFA levels on dried grass suggest that the energy

status of the bacteria was better and that they were more able to utilize ammonia immediately after feeding. It is possible that ammonia is the limiting factor for bacterial growth on dried grass. The diminution in nitrogen loss to the animal as ammonia from the rumen may have resulted in more efficient utilization but this would depend on whether the digestibility was lowered¹, and could have been determined only from nitrogen-balance studies⁵.

The higher pre-feeding levels and smaller rises in VFA on dried grass indicate that the proportion of readily available carbohydrates was lowered and that fermentation was more evenly distributed throughout the day. Hence the plethora of VFA immediately after feeding, with subsequent high specific dynamic action¹⁰ was avoided, and, since the digestibility of carbohydrates is unaffected by drying¹, it is likely that the utilization of feed energy was improved.

The steep fall of PN and FMC after feeding, presumably due to dilution, was in marked contrast to the rise in VFA and ammonia concentrations. Although the feeding of fresh grass was accompanied by about 1500 g. more water than the dried feed, there is no statistical evidence of a greater absolute or proportional fall in PN concentration. The main cause of dilution immediately after feeding appears to be salivary secretion. The possibility that protein released from fresh grass in the rumen may diminish the dilution by feed water is suggested by the proportionally greater fall in FMC on fresh grass. Further, the rate of release of water from the plant cells in the rumen is unknown, and if it is not counterbalanced by absorption, it may greatly affect the shape of the fermentation curves of all end-products.

Since the pre-feeding FMC for fresh grass was much higher, and the tendency to return to these levels was much stronger than for dried grass, it would appear that fresh grass favours greater microbial proliferation. These results provide no information on the relative fibre parasitism, but general observation indicated that it was satisfactory for both feeds. No differences were found between the morphological types of organisms present on the two feeds.

Although the estimates of RN are probably low because of the method of determination, there does not seem to be any major difference between the two feeds.

In general, the pH curves were in accordance with the VFA concentrations, the higher pre-feeding pH levels on fresh grass falling after feeding to levels similar to those on dried grass.

The increased pasture maturity between the first and second fortnights brought about a decline in crude protein content (Table 1) and changes in the pre-feeding levels of FMC, in PN levels after feeding, and in ammonia levels throughout the day. However, the increment in ammonia as a result of feeding was the same at all stages of growth. In view of the similar cellulose content of the grass in different weeks, it is understandable that the pre-feeding VFA levels were not significantly different (Table 3), but an analysis of the more soluble carbohydrates is required before comment can be made on the lack of significant differences after feeding.

Clearly, since the courses of fermentation of both the nitrogenous and carbohydrate constituents of grass are retarded by heat drying,

their rate of availability to the animal is slowed down, and therefore rumen and metabolic studies on dried grass cannot be directly applied to the grazing animal.

Because of the many significant interactions of dietary treatments with factors operating both within and between sheep, experimental designs involving large numbers of replications are obviously necessary in this type of work. The data also emphasize the importance of determining concentrations over a number of hours both before and after the animals are fed to obtain an appreciation of differences between feeds.

ACKNOWLEDGEMENT

We wish to express our appreciation to Mr. P. P. McKitterick for technical assistance.

REFERENCES

1. NEWLANDER, J. A.; JONES, C. H. 1932: *Vermont agric. Exp. Sta. Bull.* 348.
2. BATHURST, N. O.; ALLISON, R. M. 1949: *N.Z. J. Sci. Tech.* B31: 1-14.
3. LAIDLAW, R. A.; WYLAN, C. B. 1952: *J. Sci. Fd. Agric.* 3: 494-6.
4. WATSON, S. J. 1939: "The Science and Practice of Conservation: Grass and Forage Crops." Vol. 1 and 2. Fertiliser and Feeding Stuffs Journal, London.
5. CHALMERS, M. I.; CUTHBERTSON, D. P.; SYNGE, R. L. M. 1954: *J. agric. Sci.* 44: 254-62.
6. WARNER, A. C. I. 1956: *J. gen. Microbiol.* 14: 749-62.
7. WILLIAMS, V. J.; CHRISTIAN, K. R. 1956: *N.Z. J. Sci. Tech.* A38: 268-76.
8. ELSDEN, S. R. 1945: *J. exp. Biol.* 22: 51-62.
9. ANNISON, E. F.; CHALMERS, M. I.; MARSHALL, S. B. M.; SYNGE, R. L. M. 1954: *J. agric. Sci.* 44: 270-3.
10. MCCLYMONT, G. L. 1952: *Aust. J. sci. Res.* B5: 374-83.

THE EFFECT OF GROWTH SUBSTANCES ON POD-SETTING IN LUPINS

By R. F. M. VAN STEVENINCK, Crop Research Division, Department of
Scientific and Industrial Research, Christchurch

(Received for publication, 25 July 1957)

Summary

An attempt was made to prevent shedding of flowers and pods by using growth-substance sprays in order to increase the seed yield in yellow lupins (*Lupinus luteus* L.).

None of the six growth substances, which were applied at three different concentrations, caused a significant change in seed yield. *p*-chlorophenoxyacetic acid and γ -phenylbutyric acid had a slightly depressing effect on yield; 2,3,5-tri-iodobenzoic acid at 1000 p.p.m. caused a significant increase in seed size.

INTRODUCTION

One of the main defects in lupins grown commercially is the limitation in seed yield caused by the shedding of a large proportion of the flowers (Van Steveninck, in press). This behaviour is characteristic of many species of the genus.

Many reports indicate that the incidence of abscission of flowers and fruits can be reduced by applying growth substances, either as a dust or a spray at comparatively low concentrations to the entire plant or their inflorescences, e.g. on green bush snap beans with *p*-chlorophenoxyacetic acid (Wittwer and Murneek, 1946); on lima beans with *N*-*m*-tolylphthalamic acid (Rahn, 1955); on string beans with α -naphthaleneacetic acid (Fisher *et al.*, 1946); on Indian cotton with α -naphthaleneacetic acid (Bhatt and Date, 1955); on wax beans with α -naphthaleneacetic acid (Allen *et al.*, 1943). Warne (1947) found that cut inflorescences of lupins (*L. polyphyllus*) retained their flowers and buds after treatment with 0.05% solution of α -naphthaleneacetic acid or β -indolylacetic acid.

Because of these reports two experiments were carried out to test the effect of various growth substances on the seed yield of yellow lupins (*L. luteus*).

MATERIALS AND METHODS

The chemicals and the concentrations at which they were used are listed in Tables 1 and 2.

In each case an amount equivalent to 55 gallons per acre was applied as a spray using a calibrated "Zefa" hand atomizer. β -naphthoxyacetic acid (NOA) was omitted from the trials because in a previous glasshouse experiment it had shown no activity when applied at concentrations between 10–500 p.p.m.

The sprays were applied on field-grown plants of the variety Weiko II, which were grown in 21-in. drills at approximately 1-in. spacings, when the first two whorls of the main inflorescence of most plants were in bloom. As total yields were measured, close spacings of plants within rows was necessary to avoid seed production on basal

lateralis and hence possible compensatory effects on yields. As usual, flowers on apical lateralis did not produce seed.

Randomized plots consisted of 6-ft. rows; they were separated by 8-ft. buffers and each of the 5 replications was separated by two 21-in. drill strips to avoid possible effects of spray drifts. As a further precaution shields were used and sprays were applied early on a windless and sunny morning (12 January 1957). These are also the optimal conditions for penetration and distribution of substances sprayed on plants (Gustafson 1956).

Number of plants, total seed yield, and seed size were determined for each plot and from this the number of seeds per plant was calculated.

RESULTS

Experiment A

The results are summarized in Table 1.

TABLE 1. EFFECT OF GROWTH-SUBSTANCE SPRAYS ON SEED YIELD, SEED SIZE, AND NUMBER OF SEEDS (EXP. A)

Treatment		Mean No. of Plants/Plot	Mean Seed Yield g./plot	1000-Seed weight (g.)	Mean No. of Seeds/Plot
Control		64	231	149.2	1550
POA	10 p.p.m.	66	226	149.6	1513
"	30 "	65	224	156.0	1440
"	100 "	63	203	152.4	1329
CPA	2 "	60	198	148.0	1338
"	10 "	63	192	147.6	1307
"	50 "	64	185	148.0	1249
PBA	2 "	63	184	142.4	1287
"	10 "	60	186	150.4	1234
"	50 "	60	201	151.6	1316
Sig. diff. 5%		10	59	10.0	375

POA—phenoxyacetic acid.

CPA—*p*-chlorophenoxyacetic acid.

PBA— γ -phenylbutyric acid.

Although none of the treatments caused a significant change in seed yield, seed size, or number of seeds, it is probable that all treatments with the exception of POA at 10 and 30 p.p.m. had a depressing effect on seed yield and number of seeds.

Experiment B

The results of this experiment are summarized in Table 2.

Again the sprays had no significant effects on seed yield and mean number of seeds. Plants treated with TIBA at 1000 p.p.m. had

TABLE 2. EFFECT OF GROWTH-SUBSTANCE SPRAYS ON SEED YIELD, SEED SIZE, AND NUMBER OF SEEDS (EXP. B)

Treatment		Mean No. Plants/Plot	Mean Seed Yield g./plot	1000-Seed Weight (g.)	Mean No. Seeds/Plot
Control		61	201	139.6	1436
NAM	2 p.p.m.	62	196	144.0	1366
"	10 "	64	215	142.8	1505
"	50 "	66	208	146.0	1429
Duraset 20 W	100 "	64	207	144.4	1431
"	200 "	59	201	141.2	1419
"	500 "	65	195	146.4	1335
TIBA	50 "	64	191	145.2	1323
"	200 "	66	200	139.6	1439
"	1000 "	66	202	151.2	1347
Sig. diff. 5%		9	54	9.2	379

NAM— α -naphthaleneacetamide.

TIBA—2,3,5-tri-iodobenzoic acid.

Duraset 20 W—active ingredient *N-m*-tolylphthalamic acid.

significantly greater seed size, which did not result in a significant reduction in number of seeds.

In both experiments the yield of control plants was high, viz. equivalent to 1830–2100 lb. or 30.5–35 bushels per acre, which so far has been the highest yield obtained at Lincoln. Yet the mean number of seeds per plant was only 23.5 and 24.2 respectively. With a mean number of seeds per pod of 4.2, this means that the 40–50 main axis flowers of each plant produced only an average of 6 seed pods. These pods were situated on the first and second basal whorls of the inflorescence. The position of these pods was not altered by any of the spray treatments.

DISCUSSION

Results have shown that none of the growth substances were effective in raising the seed yield of lupins through prevention of flower and pod abscission. So far it appears that fruit setting can only be promoted successfully by growth substance sprays when parthenocarpic fruit development is easily induced (tomatoes, figs, grapes, etc.). However, when yields are measured in terms of seed production, results have often been disappointing or they have been contradictory; i.e. apart from the positive results quoted in the introduction many authors have reported negative results (Eaton, 1950; Ergle and McIlrath, 1952, both with cotton; Riepma, 1953, with horse beans; Luckwill, 1955, with black currants).

The condition of the crop and also climatic conditions during the fruit-setting period may influence the results of spray treatments;

e.g. when conditions for fruit setting were not favourable, positive results were obtained (Wittwer and Murneek, 1946). In our experiments, yields were substantially higher than normal and even though over 80% of the flowers dropped, one could expect that under these circumstances yield increases would be more difficult to obtain.

ACKNOWLEDGEMENTS

The author wishes to thank Professor H. N. Parton, Chemistry Department, University of Otago, for supplying the γ -phenylbutyric acid, and Mr. G. G. Taylor, Fruitgrowers' Chemicals Ltd. for a sample of Duraset 20W, and Mr. M. J. Brusse for technical assistance with the experiments.

REFERENCES

- ALLEN, T. C.; FISHER, E. H.; RIKER, A. J. 1943: Blossom Drop of Wax Beans Reduced by Growth Substances. Abstract. *Phytopathology* 33: 1109.
- BHATT, J.; DATE, R. V. 1955: Effect of α -NAA on Yield of Indian Cotton. *Nature* 175: 44.
- EATON, F. M. 1950: Influence of Growth "Hormones" on Boll Retention by Cotton Plants. *Bot. Gaz.* 111: 313-19.
- ERGLE, D. R.; MCILRATH, W. J. 1952: Response of the Cotton Plant to Late and Localised Applications of Maleic Hydrazide. *Bot. Gaz.* 114: 114-22.
- FISHER, E. H.; RIKER, A. J.; ALLEN, T. C. 1946: Bud, Blossom and Pod Drop of Canning String Beans Reduced by Plant Hormones. *Phytopathology* 36: 504-23.
- GUSTAFSON, F. G. 1956: Absorption of Co^{60} by Leaves of Young Plants and its Translocation through the Plant. *Amer. J. Bot.* 43: 157-60.
- LUCKWILL, L. C. 1955: Fruit Drop in Black Currants. II. The Effect of Naphthalenacetic Acid. *Long Ashton annu. Rep.* 1955, pp. 75-7.
- RAHN, E. M. 1955: The Effect of Certain Cultural and Growth-regulator Treatments on Pod-set and Yield in Lima Beans. *Proc. Amer. Soc. hort. Sci.* 66: 298-307.
- RIEPMA, WZN, P. 1953: Onderzoek naar de invloed van MCPA op bloei en vruchtzetting bij veldbonen. *Versl. Inst. landb. Onderz., Wageningen* 1953, pp. 110-3.
- VAN STEVENINCK, R. F. M. (in press): Factors Affecting the Abscission of Reproductive Organs in Yellow Lupins (*Lupinus luteus* L.). I. The Effect of Different Patterns of Flower Removal. *J. exp. Bot.*
- WARNE, L. G. G. 1947: Bud and Flower Dropping in Lupins. *J. R. Hort. Soc.* 72: 193-5.
- WITTWER, S. H.; MURNEEK, A. E. 1946: Further Investigations on the Value of Hormone Sprays and Dusts for Green Bush Snap Beans. *Proc. Amer. Soc. hort. Sci.* 47: 285-93.

THE ASSESSMENT OF AVAILABLE POTASSIUM IN SOILS

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Summary

Soil samples from potassium trials throughout the country, were examined by a number of different techniques. It was found that, while exchangeable K differentiates the North Island soils into K-responsive and non-responsive groups, it fails to do so in the South Island where a nitric acid extraction would be more useful. Data presented show a relationship between the usefulness of exchangeable potassium as a measure of K-supplying power, and rainfall.

INTRODUCTION

The use of exchangeable potassium as an index of the potassium-supplying power of the soil has been found valuable by some overseas workers (Chandler *et al.*, 1946; Pearson, 1952; Pratt, 1951) and of little value by others (Abel and Magistad, 1935; Rouse and Bertramson, 1949; Stewart and Volk, 1946). At this Research Station exchangeable K has been regarded as a useful pointer to potassium availability. Metson and Hurst (1953), working in the South Island with Wakanui clay loam, found exchangeable potassium to be misleading as an indicator of K supplying power, while both Haylock (1956) and Metson *et al.* (1956) have recommended successive nitric acid extractions as a means of estimating the potassium-supplying power of New Zealand soils.

Prior to this investigation, it was known that the North Island Extension Officers regarded the routine advisory K test—a one-minute extraction with Morgan's Reagent (Morgan, 1951)—more favourably than did those in the South Island. Bell (1955), in a survey of K responses over a range of North Island soil types, found good agreement between soil tests and field data. A number of South Island Officers, on the other hand, criticised the test on the ground that many soils giving low K values, showed no response in the field. In view of the differing opinions of North and South Island Officers, it was decided to examine soils from the two islands separately.

EXPERIMENTAL

Extension officers of the Department of Agriculture were asked to send in representative samples from the no-K plots of observational top-dressing trials. In judging growth responses on these observational trials, field officers employ a 0-5 rating as follows:

- 0 = no visible difference from control
- 1 = slight response
- 2 = fair response
- 3 = good response
- 4 = very good response
- 5 = excellent response

All samples received from (a) non responsive trials and (b) trials giving a response rating of 2, or above, were included in the investigation,

Samples 0-3 in. in depth were taken precisely with a tubular sampler, the study being confined to soils under pasture.

In the examination of the soils, the following methods were used:

1. A one-minute extraction with Morgan's Reagent.
2. Overnight leaching with N ammonium acetate (exchangeable K).
3. A 30-minute extraction with N ammonium acetate.
4. Boiling for 10 minutes with N nitric acid.
5. Incubation for 35 days with a cation-exchange resin (South Island soils only).
6. Ignition at 480°C. for 2 hours of the ammonium-saturated soil, followed by extraction with N ammonium acetate.

Analytical Procedures

In all cases, potassium in the final prepared solution was determined by means of the flame photometer.

Method 1. Present advisory test. A measure of soil ($4\frac{1}{3}$ ml., approx. 4 g.) is extracted for one minute with Morgan's Reagent. K is determined directly in the filtrate and results expressed as parts of K in 200,000 parts of solution. This gives a workable range of values (usually 1-20) for advisory work.

Method 2. Ten grammes of soil are leached with 350 ml. of neutral N ammonium acetate. The leachate is evaporated to dryness, digested with H_2O_2 to oxidise organic matter, and the residue taken up in N/10 HCl.

Method 3. 20 g. of soil and 50 ml. of neutral N ammonium acetate are stirred intermittently for half an hour. The soil is filtered at the pump on a Buchner funnel, washed with three 10-ml. portions of ammonium acetate, and the filtrate made up to volume in 100-ml. flasks.

Method 4. (After Metson, pers. comm.) To a 100-ml. centrifuge tube, add 4 g. of soil, 50 ml. of N nitric acid, and boil for 10 minutes. Centrifuge, and decant the supernatant liquid. Take the extract to dryness, digest twice with 5-ml. portions of 10% H_2O_2 , and then take up in 5 ml. 1 + 1 HCl and 20 ml. distilled water. Separate Fe, Al, Mn, and P by the following ammonium hydroxide-bromine precipitation (Metson 1956). Add 1 drop of $FeCl_3$ solution (146 g. of A.R. $FeCl_3$ in 500 ml. of approx. 2 N HCl). Neutralise to methyl red with 1+1 NH_4OH and add about 1 ml. in excess. Add 4 to 5 ml. of saturated bromine water, and boil for about 2 minutes. Filter, and wash with hot 2% NH_4Cl solution.

Take the filtrate to small volume, add 5-10 ml. of conc. HNO_3 (to remove ammonium salts) and take to dryness. Heat on a hot plate for half an hour (not beyond 300°C.) to make silica insoluble. Take up in 0.1 N HCl, filter, and make to volume in 50-ml. flasks.

Method 5. 7.5 g. soil and 7.5 g. Amberlite IR-120 were mixed thoroughly and placed in a leaching cup. The mixture was saturated with distilled water, the excess water drained off, and the cup stoppered and kept at 25°C. in a temperature-controlled room for 35 days. At the

TABLE 1. POTASSIUM EXTRACTED BY VARIOUS METHODS FROM NORTH ISLAND SOILS

Soil Type	Field Trial No. 16/	K Response	Routine Test	Exch. K m.e. %	30-min. Am. Ac. Extr. m.e. %	HNO ₃ Extr. m.e. %	Ign. Am. Satd. Soil m.e. %
Karaka complex	F.I.C.*	—	11	1.11	0.93	1.07	0.32
Kairanga clay loam	2/2508	—	12	1.06	1.03	2.16	>2.6
Tarawera gravel	1/2331	—	16	0.93	0.76	1.09	0.77
Netherton clay	1/2529	—	6	0.74	0.67	0.70	0.83
Ardmore peaty loam	1/2448	—	5	0.71	0.60	0.56	0.36
Red Hill sandy clay loam	1/2080	—	8	0.62	0.56	0.74	0.28
Weymouth silt & clay loam	1/2435	—	5	0.58	0.51	0.42	0.81
Manawatu loam	1/2552	—	6	0.57	0.54	0.67	1.21
Rukuhia peat	15/34	+	3	0.55	0.39	0.14	0.12
Waitoa-Waihou complex	1/2527	—	6	0.54	0.44	0.70	0.44
Patumahoe clay loam	1/2626	+	5	0.52	0.41	0.56	0.30
Waihou sandy loam	1/2015	+	7	0.52	0.43	0.51	0.62
New Plymouth sandy loam (hill)	2/2467	+	5	0.49	0.42	0.42	0.64
Whananaki sand	1/2866	+	7	0.43	0.36	0.58	0.42
New Plyomuth black loam	2/2834	+	5	0.42	0.31	0.42	0.57
Kinohaku silt loam	1/2522	+	3	0.40	0.36	0.42	0.44
Te Rauamoia silt loam	1/2535	+	3	0.40	0.34	0.38	0.40
Karaka complex	1/2367	+	5	0.40	0.36	0.46	0.37
Horotiu sandy loam	1/2327	+	4	0.37	0.32	0.46	0.54
Wairere silt loam & clay loam	Pilot	+	3	0.37	0.35	0.36	0.52
Mapiu silt loam	1/2521	+	3	0.36	0.31	0.34	0.46
Brookby clay loam & clay	1/2439	+	4	0.36	0.34	0.45	0.39
Ohaupo silt loam	1/2298	+	3	0.34	0.27	0.42	0.69
Patua sandy loam	2/2648	+	6	0.31	0.28	0.43	0.68
Te Kuiti silt loam	1/1942	+	2	0.30	0.25	0.29	0.80
Stratford sand	2/2461	+	5	0.30	0.23	0.40	0.48
Oropi shallow sand (hill)	1/2129	+	4	0.30	0.28	0.43	0.55
Ohakea loam	2/2530	+	5	0.29	0.26	1.06	1.38
Stratford sand	2/2455	+	6	0.28	0.29	0.37	0.61
Karaka clay loam	F.I.C.*	+	3	0.28	0.25	0.35	0.29
Marton clay loam	Exp. H	+	3	0.25	0.22	0.45	0.79
Kiripaka loam	1/2044	+	2	0.23	0.19	0.27	0.21
Halcombe silt loam	2/2580	+	3	0.19	0.16	0.40	0.44
Patea sand	2/2657	+	3	0.18	0.15	0.35	0.52

* Farm Improvement Club, Pukekohe.

TABLE 2. POTASSIUM EXTRACTED BY VARIOUS METHODS FROM SOUTH ISLAND SOILS

Soil Type	Field Trial No. 16/	K Response	Routine Test	Exch. K m.e. %	30-min. Am. Ac. Extr. m.e. %	HNO ₃ Extr. m.e. %	Amber- lite IR-120 m.e. %	Ign. Am. Satd. Soil m.e. %
(Waratah clay loam)	3/3379	—	13	1.35	1.26	3.81	4.34	>2.6
Okuku silt loam	3/2992	—	16	1.01	0.95	1.44	1.38	0.68
Chertsey silt loam	3/3181	—	11	0.92	0.67	1.49	1.36	1.88
Wehenga silt loam	4/1692	—	7	0.80	0.67	1.22	1.13	1.87
Claremont silt loam	3/3057	—	9	0.69	0.67	1.48	1.28	1.35
(Mataura soils)	4/2218	—	8	0.60	0.56	1.73	1.37	2.02
Te Houka silt loam	4/1954	—	8	0.60	0.59	0.88	0.78	1.46
(Taitapu silt loam, peaty phase)	3/3279	—	4	0.51	0.49	0.86	0.85	1.52
(Hinahina soils)	4/2663	+	5	0.49	0.43	0.77	—	1.00
(Wehenga silt loam)	4/2216	—	7	0.47	0.45	1.22	—	1.81
Not identified	4/2327	—	6	0.46	0.44	0.92	0.71	1.80
Ruapuna silt loam	3/3182	—	4	0.46	0.40	0.93	0.80	2.07
(Ngapara fine sandy loam)	4/2251	—	9	0.44	0.45	1.68	1.57	1.21
(Soil from phonolite)	I.150	—	4	0.44	0.38	0.65	—	1.47
Claremont silt loam	3/2959	—	6	0.42	0.36	1.03	0.87	1.34
(Idaburn stony loam)	4/2289	—	4	0.40	0.32	2.05	2.29	1.16
Claremont silt loam	3/2876	—	5	0.33	0.30	0.59	0.56	1.32
Not identified	3/2951	+	4	0.31	0.24	1.70	1.37	0.71
Ahaura silt loam	3/2538	+	3	0.30	0.27	1.32	1.06	1.36
Tisbury complex	4/2195	+	4	0.30	0.29	0.43	0.45	0.40
Not identified	3/3423	+	4	0.29	0.28	0.50	0.38	0.24
Not identified	3/3203	—	4	0.28	0.27	0.78	0.62	1.07
Warepa silt loam	4/2637	+	4	0.28	0.32	0.50	—	1.29
Waimumu silt loam	4/2200	+	3	0.27	0.23	0.38	0.36	0.95
Not identified	3/3422	+	2	0.27	0.29	0.50	0.42	0.45
Kaiapoi silt loam	3/3103	—	3	0.27	0.22	0.90	0.96	1.18
Waikiwi silt loam	4/2618	+	3	0.26	0.27	0.52	—	0.83
Warepa silt loam	4/2699	+	2	0.19	0.14	0.35	—	1.51
Warepa silt loam	4/2636	+	2	0.19	0.22	0.51	—	1.32
Mairaki silt loam	3/2994	—	3	0.18	0.18	0.90	0.51	1.13
Waikiwi silt loam	4/2617	+	2	0.17	0.18	0.40	—	0.77
(Warepa silt loam)	4/2640	+	2	0.16	0.18	0.48	—	1.15
Warepa silt loam	4/1869	+	3	0.15	0.13	0.27	0.26	0.57
Claremont silt loam	3/2877	—	2	0.12	0.10	0.54	0.47	1.06

NOTE: Soil names in brackets are pending final classification.

end of that period, soil plus resin was leached with N ammonium acetate and K was determined as in Method 2.

Method 6. As given by Kolterman and Truog (1953) for the determination of "fixed" potassium.

RESULTS

Results are given in Tables 1 and 2. As it is not evident from the tables which procedure gives the best differentiation into K-responsive and non-responsive groups, results for the first four methods are also depicted graphically, soils being arranged in descending order of K. Non-responsive soils are represented by black columns, responsive by white. Using this method of presentation, it is evident that a good K test would show a block of black columns on the left and a block of white on the right, with a few indeterminate soils in between.

DISCUSSION

North Island Soils

A study of Fig. 1 shows that

- (a) In the present advisory test, no responses are recorded where the test is 8 or above while responses are always found where the test is 4 or below. The indeterminate fraction 5-7 is fairly large, forming 44% of the soils under investigation. As the remaining methods were carried out on a weight basis, the advisory test was repeated, using a 4-g. weight of soil. Figures are not presented here, but results were very similar to that found on a volume basis, with approximately the same indeterminate fraction.
- (b) Exchangeable K differentiates the soils into responsive and non-responsive groups, the indeterminate fraction lying between 0.52-0.57 m.e. %.

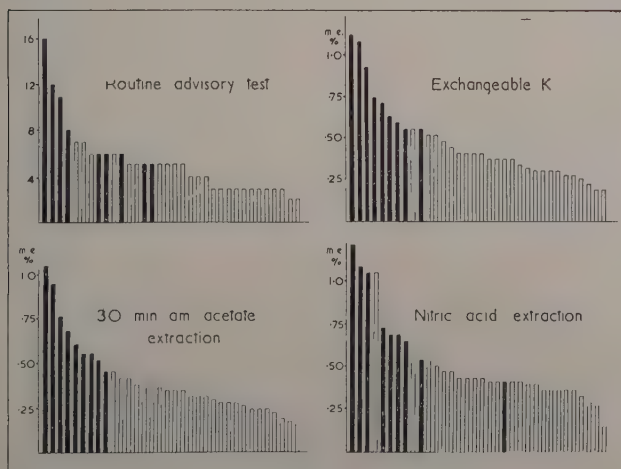


Fig. 1.—North Island soils: ability of various chemical methods to discriminate between K-responsive and non-responsive soils.

- (c) The 30-minute ammonium acetate extraction also differentiates well, the figures obtained giving a cut-off at 0.44 m.e. %.
- (d) The nitric acid extraction does not differentiate the soils as well as an ammonium acetate extraction.

The procedure of Kolterman and Truog for the determination of fixed potassium was investigated over a large range of soil types. The only modification made to the method was the employment of an ignition temperature of 480°C., as preliminary work showed a small loss of potassium at 500°C. On the authors' reasoning, the method would be expected to apply in particular to soils containing clay minerals of the 3-layer type. It was not unexpected when no general application was found in the present survey. Neither, however, did the method discriminate successfully between responsive and non-responsive soils of the type to which the test would appear adapted. In a number of cases, where organic matter was high, exchangeable K exceeded that found following the first ignition of the ammonium-saturated soil, thus making their recommendation for the rapid calculation of fixed potassium inapplicable.

Initially, it appeared that a simple ignition of the soil, followed by an ammonium acetate extraction, would be of value in assessing the K-supplying power of the soil. However, investigation over a greater range of soil types gave disappointing results, and it has been concluded that methods involving ignition of the soil are not a satisfactory means of assessing the potassium-supplying power of New Zealand soils.

Within the responsive block, there is no close connection between the level of exchangeable potassium and the order of response assessed in the field. For example, Marton loam, a yellow-grey earth, has an exchangeable-K content of 0.25 m.e. %, but responses are not as great as shown by some K-responsive soils having higher levels of exchangeable K. In spite of this defect, exchangeable-K figures have successfully differentiated between all the responsive and non-responsive North Island soils examined.

South Island Soils

It is evident (Fig. 2) that the present advisory test, exchangeable K, and the 30-minute ammonium acetate extraction, fail to differentiate the soils into responsive and non-responsive groups. It was thought that in the four non-responsive soils giving exchangeable-K values below 0.3 m.e. %, some factor other than potassium may have been limiting growth. However, field officers reported vigorous growth on these trials, making this suggestion improbable.

Nitric Acid Extraction. This gives the best differentiation. Three soils, however, fall out of line:

(a) Unclassified soil type — trial 16/3/2951

(b) Ahaura silt loam — trial 16/3/2538

These two K-responsive soils from the west-coast area have been examined by Metson who has also found them anomalous by the Δ K method (Metson *et al.*, 1956). Whether the potassium is coming from the organic matter present or from some mineral not occurring generally has not been determined. It is probable that the soils from this high-

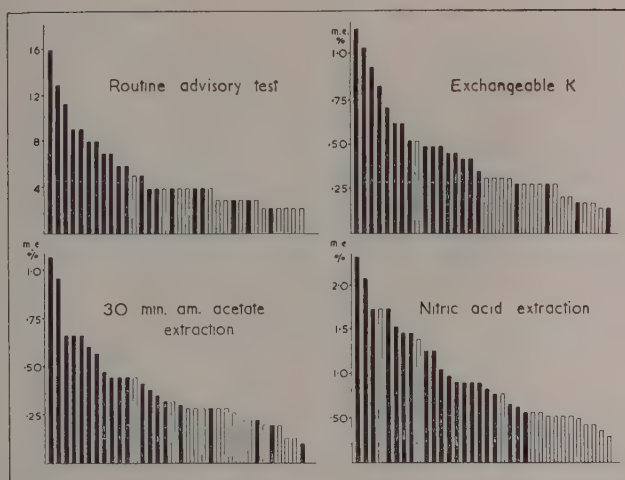


Fig. 2.—South Island soils: ability of various chemical methods to discriminate between K-responsive and non-responsive soils.

rainfall area are more akin to the North Island soils and could be classified on an exchangeable-K basis (exchangeable K is 0.3 m.e.% in both cases).

(c) A third soil — 16/4/2663 — is from a fairly new trial. It will be interesting to see whether the potash response is sustained.

Potassium extracted after incubation with the Amberlite IR—120 was highly correlated with that extracted by the *N* nitric acid ($r = .98$). This is in agreement with Pratt's (1951) work on Iowa soils, the correlation between K extracted by Dowex 50 and *N* nitric acid being 0.957.

Kolterman and Truog's "fixed" potassium, and combinations of this with exchangeable K, again failed to discriminate between responsive and non-responsive soils.

GENERAL

Improvement in the Present Advisory Test for North Island Soils

The better differentiation shown by the 30-minute ammonium acetate extraction over the one-minute shake with Morgan's Reagent on the North Island soils, could be due to (a) the extra time of shaking, (b) the higher pH, (c) the different cation in the extracting solution, or a combination of these factors. Investigation of each of these, using a range of soils, showed that the difference was due to the NH_4 ion. With a view to improving the existing test, various soil : solution ratios and times of shaking with ammonium acetate were tried. The most acceptable method was given by a ratio of one measure of soil to 20 ml. of extracting solution (approx. a 1 : 5 soil : solution ratio) with a two minute shake. Using this method, all non-responsive North Island soils gave more than 30 p.p.m. K in the filtrate, responsive soils less than 25 p.p.m. K, with a 25–30 p.p.m. K fraction being indeterminate. Only 4 soils, or 12% of those examined, fall in the indeterminate fraction.

The superiority of NH_4 -salt extractants has also been pointed out by Pizer (1952) on south-eastern soils in England, Morgan's Reagent having been replaced by an ammonium nitrate extractant in the National Advisory Service.

Exchangeable Potassium as an Indicator of the Potassium-supplying Power of the Soil

It is clear that exchangeable-K levels above 0.55 m.e.% are useful in predicting fertiliser responses in the North Island and in the wetter west-coast area of the South Island, but not in the drier parts of the South Island. Mean annual-rainfall figures (from the rainfall station nearest to the site of the trial) have been plotted against exchangeable-K values. From Fig. 3, which includes all the trials from both islands, it will be seen that, as far as the soils examined are concerned,

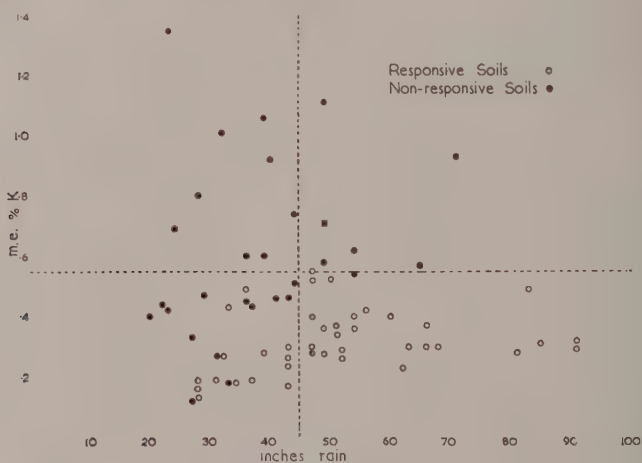


Fig. 3.—Usefulness of exchangeable K as an index of K-supplying power under varying rainfall conditions.

- (1) Exchangeable K differentiates the soils well where rainfall is above 45 in. a year.
- (2) Exchangeable-K levels above 0.5 m.e.% are associated with non-responsive soils, irrespective of rainfall.
- (3) Low exchangeable-K levels cannot be used to forecast potassium responses where rainfall is below 45 in. a year.

In this connection, the observation of Schmitz and Pratt (1953) in commenting on the varying usefulness of exchangeable-K levels as found by different workers, that exchangeable K can be expected to be the most important factor in K supply among highly weathered soils, is of interest.

Normal Nitric Acid Extractions

Unfortunately the analytical method is tedious. Semb and Uhlen (1955) do not remove the Fe and Al before flaming the nitric acid

extract, so that it might be possible to simplify the procedure. However, a glance at the table of exchangeable-K levels of the South Island soils shows that, with the exception of trial 16/4/2663, no responses are recorded where exchangeable K is above 0.3 m.e.%. Examination of the South Island soils by the 2-minute ammonium acetate shake disclosed that all non-responsive soils gave a level of 25 p.p.m. K or more in the filtrate. Hence a preliminary sorting out could be made by the proposed rapid test, and it would then be necessary to examine by the nitric acid method only those soils where the rapid ammonium acetate extraction gave less than 25 p.p.m. K in the filtrate. Repeat nitric acid determinations have shown the method to be reproducible, the response level for South Island soils being 0.55 m.e.%.*

CONCLUSIONS

Over the country as a whole, if exchangeable K is above 0.6 m.e.%, responses to potash are very unlikely. The converse does not hold.

In the North Island, potassium responses are improbable where exchangeable K is above 0.6 m.e.%, and probable below 0.5 m.e.%. The present advisory test using Morgan's Reagent as the extracting medium, would be better replaced by an ammonium acetate extraction.

On certain South Island soil types, exchangeable potassium is a poor guide to the potassium-supplying power of the soil. The use of a nitric acid extractant, after a preliminary separation of soils by a rapid ammonium acetate extraction, shows promise. Some west-coast soils give anomalous results by the nitric acid method and would be better included with North Island soils.

A study of exchangeable-potassium values in relation to rainfall suggests that the employment of exchangeable K as an index of potassium-supplying power will be useful in areas where rainfall exceeds 45 in. a year, but of little value in the drier parts of the country.

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REFERENCES

- ABEL, F. A. E.; MAGISTAD, O. C. 1935: Conversion of Soil Potash from Non-replaceable to the Replaceable Form. *J. Amer. Soc. Agron.* 27: 437-45.
BELL, J. E. 1955: *N.Z. J. Agric.* 90: 81.

* Since this paper was written, a 25-minute nitric acid extraction at 113°C. as described by Pratt and Morse (1954) has been investigated, and appears promising as a suitable method for routine soil analyses.

- CHANDLER, R. F.; PEECH, M.; BRADFIELD, R. 1946: A Study of Techniques for Predicting the Potassium and Boron Requirements of Alfalfa. *Proc. Soil Sci. Soc. Amer.* 10: 141-6.
- HAYLOCK, O. F. 1956: A Method for Estimating the Availability of Non-exchangeable Potassium. *Rep. 6th Congr. Soil Sci. Comm. II.* pp. 403-8.
- KOLTERMAN, D. W.; TRUOG, E. 1953: Determination of Fixed Soil Potassium. *Proc. Soil Sci. Soc. Amer.* 17: 347-51.
- METSON, A. J. 1956: Methods of Chemical Analysis for Soil Survey Samples. *N.Z. Soil Bur. Bull.* 12: 107.
- METSON, A. J.; ARBUCKLE, R. H.; SAUNDERS, MARY L. 1956: The Potassium-supplying Power of New Zealand Soils as Determined by a Modified Normal Nitric Acid Method. *Rep. 6th Congr. Soil Sci. Comm. II.* pp. 619-27.
- METSON, A. J.; HURST, F. B. 1953: Effects of Sheep Dung and Urine on a Soil under Pasture at Lincoln, Canterbury, with Particular Reference to Potassium and Nitrogen Equilibria. *N.Z. J. Sci. Tech.* 435: 327-59.
- MORGAN, M. F. 1941: Chemical Soil Diagnosis by the Universal Soil-testing System. *Conn. agric. Exp. Sta. Bull.* 450.
- PEARSON, R. W. 1952: Potassium-supplying Power of Eight Alabama Soils. *Soil Sci.* 74: 301-9.
- PIZER, N. H. 1952: Evaluation of Soil Analysis for Advisory Purposes. *Trans. int. Soc. Soil Sci. Joint Mtg. Comm. II & IV, Dublin.* 2: 364-72.
- PRATT, P. F. 1951: Potassium Removal from Iowa Soils by Greenhouse and Laboratory Procedures. *Soil Sci.* 72: 107-17.
- PRATT, P. F.; MORSE, H. H. 1954: Potassium Release from Exchangeable and Non-exchangeable Forms in Ohio Soils. *Ohio agric. Exp. Sta. Res. Bull.* 747.
- ROUSE, R. D.; BERTRAMSON, B. R. 1949: Potassium Availability in Several Indiana Soils: Its Nature and Methods of Evaluation. *Proc. Soil. Sci. Soc. Amer.* 14: 113-23.
- SCHMITZ, G. W.; PRATT, P. F. 1953: Exchangeable and Non-exchangeable Potassium as Indexes to Yield Increases and Potassium Absorption by Corn in the Greenhouse. *Soil Sci.* 76: 345-53.
- SEMB, G.; UHLEN, G. 1955: A Comparison of Different Analytical Methods for the Determination of Potassium and Phosphorus in Soil, Based on Field Experiments. *Acta. agric. scand.* 1.
- STEWART, E. H.; VOLK, N. J. 1946: Relation between Potash in Soils and that Extracted by Plants. *Soil Sci.* 61: 125-9.

EVALUATION OF GENERAL AND SPECIFIC COMBINING ABILITY IN PERENNIAL RYEGRASS (*Lolium perenne* L.)

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Summary

A comparison was made of the relative magnitude of general and specific combining ability in diallel crosses of two groups of perennial ryegrass.

The relationship between visual yield scores and green forage weight was studied.

General combining ability was generally greater than specific combining ability in non-inbred plants unselected for combining ability, whereas the reverse was found for plants previously selected for combining ability.

Specific combining ability estimates calculated from visual yield scores at different seasons were highly correlated with each other and with those for spring forage yield.

The correlation between autumn and winter visual yield scores was significantly greater than either autumn or winter with spring scores.

A highly significant correlation was obtained between visual yield estimates and green forage yield.

Some evidence for reciprocal differences was found.

INTRODUCTION

The recombination of superior clones or plants high in combining ability into synthetic strains appears to offer considerable merit in forage crop breeding. Theoretically the best estimates of combining ability are obtained from a comparison in diallel crosses of all possible single crosses. Diallel crossing, however, is not feasible when the number of plants to be evaluated is large. As a consequence, open-pollination, topcross, or polycross progeny tests are used to evaluate selected plants and to estimate their combining ability. This paper compares the relative magnitude of general and specific combining ability, using diallel crosses, in two groups of perennial ryegrass plants, one group having been previously selected for combining ability and the other not.

LITERATURE

Sprague¹ and Tatum (1942) found that, in previously untested lines of *Zea mays*, genes affecting general combining ability were of more importance in determining yield differences, whereas in previously selected material, genes conditioning specific combining ability were of greater importance.

Bolton (1948) reported differences in specific combining ability among 13 inbred and 13 non-inbred clones of *Medicago sativa* for forage and seed yield. Knowles (1950) found that the variance for specific

combining ability was greater than for general combining ability in *Bromus inermis* whereas the reverse was obtained in *Agropyron cristatum*. In *Bromus inermis* the presence of a variable number of inbred plants was thought to have influenced the results.

Oldemeyer and Hanson (1955) reported differences in 5 of 7 *Dactylis glomerata* plants in specific combining ability for forage yield. Kalton and Leffel (1955) in a comparison of all possible single crosses among 11 *Dactylis glomerata* clones, unselected for combining ability, observed that the variance attributable to general combining ability was greater than that for specific combining ability for yield and other characters.

Kalton *et al.* (1952, 1955) found, in *Dactylis glomerata*, that characters such as spring vigour, panicle number, and aftermath, were highly correlated with forage yield. Brigham and Wilsie (1955) reported close associations between scores for spread, vigour, and density with forage yield. They suggested that an overall rating for vegetative vigour could be used as a basis for selecting spaced plants of Ladino clover (*Trifolium repens* Leyss).

Glenday (unpublished) found that with *Lolium* sp. approximately twenty per cent more plants are required for visual yield scores to give the same efficiency as green forage weights.

MATERIALS AND METHODS

The material studied in this investigation was chosen from populations of ryegrass plants being used by Corkill (1949, 1956) in the plant improvement programme of the Grasslands Division at Palmerston North. The material chosen involved all possible single crosses and their reciprocals for each of 2 groups, A and B, of non-inbred perennial ryegrass plants. Group A consisted of 5 plants which were the most similar for general combining ability, with respect to forage yield, based upon the performance of all possible single crosses among 12 unrelated plants. Group B was composed of 10 plants unselected for general combining ability. It consisted of a random sample of plants which survived preliminary evaluation.

All progenies had been sown in the glasshouse and transplanted to the field using a 2 × 2 ft. spacing. Group A was transplanted in May 1954, the design being a randomized complete block with 10 replicates. All crosses and reciprocals were represented by 6-plant plots. Group B was transplanted in May 1955, in a split-plot design with 6 replicates. The single crosses were placed in whole plots of 2 rows of 5 plants each, the 2 sub-plots of 5 plants being reciprocals. The total green weight (oz.) of each plot was taken 3 times for Group A in the spring of 1954, (4 October, 11 and 30 November) and once for Group B in the spring of 1956 (16 November). Green weights were taken when the plants were approximately 12–14 inches high. All plants were cut uniformly to a height of 1½ inches. Visual yield scores were made for the Group B plants 3 times during 1956, namely in the autumn (27 April), in the winter (6 August) and in the spring (10 October).

Both groups were analysed using the procedure given by Kempthorne (1952) for diallel crosses. Estimates of the general and specific combining ability for each of the plants in both groups were

determined by the method of Sprague and Tatum (1942). The formula for estimating specific combining ability given by Rojas and Sprague (1952) was used. Variance components were determined to estimate the relative magnitude of general and specific combining ability and environmental variability using the formulae given by Rojas and Sprague (1952). Correlation coefficients were calculated to evaluate the interrelationships among visual yield scores taken in different seasons and with green forage yields for Group B.

RESULTS

The data for group A are given in Tables 1, 2, 3, and 8. The green forage weights (Table 1) averaged over all single crosses showed little difference between plants within each cut. An exception was the third cut of plant C where the forage yield was considerably lower than those of the other plants.

TABLE 1. GREEN FORAGE WEIGHTS¹ (OZ.) AND RANKS FOR FIVE NON-INBRED PERENNIAL RYEGRASS PLANTS, AVERAGED FOR ALL SINGLE CROSSES, GROUP A

Plant	First Cut		Second Cut		Third Cut		All Cuts	
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank
A	33.5	2	33.0	2	47.0	2	37.8	2
B	33.6	1	33.9	1	48.8	1	38.8	1
C	33.3	3	32.8	3	41.9	5	36.0	5
D	32.1	4	32.2	4	46.0	4	36.8	4
E	32.4	5	31.5	5	46.6	3	37.2	3
Mean	33.0		32.7		46.1		37.2	
S.E. of means ²	1.5		1.7		2.8		1.9	

¹ Totals of six plants.

² Calculated from "Crosses in plants" Table 2.

Estimates of general combining ability, S^2_g , were small and negative except for the third cut and interaction with cuts. This was primarily due to plant C where forage yield was about average for the first two cuts but considerably below average for the third cut. Estimates of specific combining ability, S^2_s , were greater than those for general combining ability save that for interaction with cuts. The low interaction with cuts for S^2_s indicated that the performance of single crosses within plants was consistent for all three cuts.

General and specific combining ability estimates for each plant are shown in Table 3. The estimates for specific combining ability were generally greater than those for general combining ability. The most marked exceptions were the estimates of general combining ability of plants B and C for the third cut.

TABLE 2. ANALYSES OF VARIANCE OF GREEN FORAGE YIELDS OF DIALLEL CROSSES AND RECIPROCALLS AMONG FIVE NON-INBRED PERENNIAL RYEGRASS SELECTIONS, GROUP A

Source of Variation	d.f.	First Cut	Second Cut	Third Cut	All Cuts	Interaction with Cuts	
		m.s.	m.s.	m.s.	m.s.	d.f.	m.s.
Blocks	9	200.3**	267.0**	187.4**	302.1**	18	177.6**
Plants	4	48.9	80.3	699.6	366.4	8	231.2**
Crosses in plants	5	88.8*	109.8**	307.5**	430.7**	10	37.2
Reciprocal	10	29.8	37.1	139.4**	133.5	20	36.4
Error	171	38.6	25.0	50.2	84.3	337	22.6
S^2_r †		-0.44	0.60	4.46	0.82		1.09
S^2_g		0.66	-0.49	6.54	-0.36		3.23
S^2_s		2.51	4.23	12.87	5.77		1.13
Coeff. var.		18.8	15.3	15.4	24.7		10.3

** Significant at 1% level, * significant at 5% level. The error m.s. was used to test all sources of variation for significance except "Plants" where "Crosses in plants" was used.

† S^2_r , S^2_g and S^2_s are estimates of variance components for reciprocal differences, general and specific combining ability respectively.

TABLE 3. ESTIMATES OF GENERAL AND SPECIFIC COMBINING ABILITY BASED UPON DIALLEL CROSSES AMONG FIVE NON-INBRED PERENNIAL RYEGRASS PLANTS, GROUP A

Plant	First Cut		Second Cut		Third Cut		All Cuts	
	S^2_g †	S^2_s	S^2_g	S^2_s	S^2_g	S^2_s	S^2_g	S^2_s
A	0.01	1.11	-0.17	1.20	1.00	4.10	-0.46	-0.54
B	0.14	0.13	2.12	1.25	12.73	0.79	2.94	-2.05
C	-0.36	-1.18	-0.30	0.98	30.39	8.74	1.66	-0.73
D	0.79	2.77	0.07	4.40	-0.66	10.84	-0.99	3.12
E	0.11	2.34	1.97	4.21	-0.17	14.12	-0.83	3.36
Mean	0.14	1.03	0.74	2.41	8.66	7.72	0.46	0.63

† S^2_g and S^2_s are estimates of general and specific combining ability respectively.

The differences between reciprocals was significant only for the third cut. The reciprocal yields showed that the significance was entirely due to plant C. In all four single crosses involving C, the forage yield

was less, ranging from 8% to 33%, when C was used as the female parent compared with C used as the male parent. The same tendency was noted in the other two cuts, although the differences were too small to be significant.

Visual yield scores and green forage yields for group B are presented in Table 4. The analyses of variance (Table 5) indicate significant differences both among plants and for single crosses within plants for

TABLE 4. VISUAL YIELD SCORES, GREEN FORAGE WEIGHTS¹ (oz.) AND RANKS FOR TEN NON-INBRED PERENNIAL RYEGRASS PLANTS AVERAGED OVER ALL SINGLE CROSSES, GROUP B

Plant	Visual Yield Score								Forage Yield Spring	
	Autumn		Winter		Spring		All Seasons		Yield	Rank
	Score	Rank ²	Score	Rank	Score	Rank	Score	Rank		
1	11.4	10	9.2	10	11.9	10	10.8	10	51.4	10
2	11.4	9	11.1	7	12.3	9	12.0	8	56.3	9
3	14.9	2	14.5	1	13.7	6	14.4	3	59.7	7
4	14.9	1	13.8	2	14.5	5	14.4	2	63.2	5
5	12.3	8	10.8	8	14.2	4	12.4	7	63.9	4
6	14.6	4	13.6	3	14.9	3	14.4	4	69.5	2
7	13.2	6	12.7	5	15.0	2	13.6	5	67.7	3
8	12.6	7	10.2	9	13.3	8	12.0	8	59.5	8
9	14.8	3	13.4	4	15.8	1	14.7	1	71.7	1
10	14.2	5	11.1	6	13.4	7	12.9	6	63.0	6
Mean	13.6		12.0		13.9		13.2		62.6	
S.E. of means	0.7 ³		0.8		0.7		0.7		3.1	

¹ Totals of five plants.

² Based upon an additional decimal.

³ Calculated from "Crosses in plants" Table 5.

all three visual yield scores and for forage yield. The highly significant interactions of plants and their crosses with seasons, indicate that the average performance of certain plants and of certain crosses was not consistent from season to season. A comparison of the rank order of the 10 plants for visual yield scores shows a close agreement between autumn and winter rankings. The spring rank order, however, differed considerably from those of the autumn and winter. For example, plants 3 and 4 which ranked highest for visual yield score for the autumn and winter estimates were ranked fifth and sixth in the spring.

TABLE 5. ANALYSES OF VARIANCE OF VISUAL YIELD SCORE AND GREEN FORAGE YIELD OF DIALLEL CROSSES AND RECIPROCALLS AMONG TEN NON-INBRED PERENNIAL RYEGRASS SELECTIONS, GROUP B

Source of Variation	d.f.	Visual Yield Score					Forage Spring m.s.
		Autumn m.s.	Winter m.s.	Spring m.s.	All Seasons m.s.	Interaction with Seasons† m.s.	
Blocks	5	17.6*	65.2**	77.8**	121.5**	19.6**	2924.7**
Plants	9	200.2**	384.4**	182.7**	632.3**	67.5**	4610.9**
Crosses in plants	35	23.0**	30.8**	26.4**	71.6**	4.3**	509.0**
Error (a)	220	7.0	6.3	7.2	14.7	2.9	170.0
Reciprocal	44	7.7**	7.3**	3.8	14.1	2.3**	86.2
Error (b)	236	4.3	3.8	4.5	10.3	1.2	96.2
S ² r†		0.56	0.57	-0.13	0.21	0.19	-1.66
S ² g		1.85	3.68	1.63	1.95	0.66	42.7
S ² s		1.33	2.05	1.60	1.58	0.12	28.3
Coeff. var.		19.5	20.8	19.4	29.1	13.0	20.8

** Significant at 1% level, * significant at 5% level. The error m.s. was used to test all sources of variation for significance except "Plants" where "Crosses in plants" was used.

† S²r, S²g, and S²s are estimates of variance components for reciprocal differences, general and specific combining ability respectively.

‡ d.f. for interaction with seasons are double those for the other items.

The estimates of general combining ability (Table 6) were all greater than those for specific combining ability. The estimates, however, of specific combining ability for plants 4 and 5 were larger than those for general combining ability in 9 out of 10 comparisons. The correlation coefficients (Table 7) show a close association among the estimates of specific combining ability for visual yield score from season to season, and with those of spring forage yield. Similar correlations for general combining ability were smaller and non-significant in 5 of 7 comparisons.

Estimates of the relative importance of general, specific and environmental variability, based upon the method of Rojas and Sprague (1952) are given in Table 8. The relative importance of the variability associated with specific combining ability was similar for both group A and B. The general combining ability, however, for group B was considerably greater than for group A.

Evidence of reciprocal differences was found in group B for the autumn and winter visual yield scores and for interaction with season. Unlike group A no consistent pattern was observed.

TABLE 6. ESTIMATES OF GENERAL, S^2_g AND SPECIFIC, S^2_s , COMBINING ABILITY BASED UPON DIALLEL CROSSES AMONG TEN NON-INBRED PERENNIAL RYEGRASS PLANTS, GROUP B

Plant	Visual Yield Score								Forage Yield Spring	
	Autumn		Winter		Spring		All Seasons		S^2_g	S^2_s
	S^2_g	S^2_s	S^2_g	S^2_s	S^2_g	S^2_s	S^2_g	S^2_s		
1	6.09	0.12	6.91	0.07	5.25	0.33	6.95	0.18	156.22	-2.35
2	0.86	0.31	0.28	1.06	3.04	0.47	1.56	0.45	48.44	9.57
3	2.12	1.78	10.97	3.66	-0.03	1.20	1.81	2.01	9.24	18.81
4	2.31	2.59	6.06	5.12	0.40	4.27	1.89	3.86	-1.13	83.48
5	1.91	2.60	0.75	3.40	0.04	3.38	0.63	3.09	0.63	57.56
6	1.29	0.52	5.08	1.25	1.22	1.01	1.77	0.85	58.95	21.44
7	0.07	1.41	1.49	1.47	1.34	1.14	0.21	1.11	30.98	6.58
8	1.11	0.32	2.30	0.57	0.39	0.62	1.56	0.36	10.29	12.75
9	1.90	0.44	4.01	-0.08	4.58	0.91	2.79	0.35	104.11	18.90
10	0.44	0.36	0.24	0.72	0.24	0.42	0.02	0.43	0.33	2.76
Mean	1.81	1.05	3.81	1.72	1.65	1.38	1.92	1.27	41.86	22.95

TABLE 7. INTERSEASON AND INTERCHARACTER CORRELATIONS OF ESTIMATES OF SPECIFIC AND GENERAL COMBINING ABILITY FROM INDIVIDUAL PLANTS OF PERENNIAL RYEGRASS, GROUP B

Character	Forage Yield	Visual Yield Score		
		Autumn	Winter	Spring
Spring yield	—	0.83 ²	0.83	0.98
Autumn score	0.69 ¹	—	0.92	0.96
Winter score	0.23	0.55	—	0.86
Spring score	0.95	0.56	0.06	—

¹ Correlations below diagonal are for estimates of general combining ability.

² Correlations above diagonal are for estimates of specific combining ability.

$n = 10$; value of r required for significance at 5% level is .632, at 1% level is .765.

TABLE 8. ESTIMATES OF THE RELATIVE IMPORTANCE OF GENERAL AND SPECIFIC COMBINING ABILITY AND ENVIRONMENTAL VARIABILITY AMONG TWO NON-INBRED PERENNIAL RYEGRASS SELECTIONS

Green Forage Yield Group A					
Source of Variation	First cut	Second cut	Third cut	All cuts	Interaction with cuts
G _A ¹	-3.3	-3.5	17.2	-0.8	21.4
G _S	6.3	15.0	16.9	6.5	3.7
G _E	97.0	88.5	65.9	94.3	74.9

Group B

Source of Variation	Visual Yield Score					Spring Forage Yield
	Autumn	Winter	Spring	All Seasons	Interaction with seasons	
G _A	30.6	47.0	26.9	30.1	19.4	30.2
G _S	11.1	13.1	13.3	10.0	7.8	2.7
G _E	58.3	39.9	59.8	59.9	72.8	67.1

¹G_A G_S, G_E refer to general, specific and environmental variability respectively.

TABLE 9. INTERSEASON AND INTERCHARACTER CORRELATIONS FOR VISUAL YIELD SCORES AND GREEN FORAGE YIELDS IN PERENNIAL RYEGRASS, GROUP B

Character	Forage Yield Spring	Visual Yield Score		
		Autumn	Winter	Spring
Spring yield	—	0.50 ²	0.58	0.89
Autumn score	0.66 ¹	—	0.84	0.63
Winter score	0.66	0.89	—	0.65
Spring score	0.96	0.74	0.54	—

¹ Correlations below diagonal are for means of single crosses.
n = 45, value of r required for significance 1% level is .38.

² Correlations above diagonal are for individual plots.
n = 540, value of r required for significance 1% level is .115.

Two sets of correlation coefficients for group B are shown in Table 9. Those below the diagonal were calculated from means of single crosses whereas those above the diagonal were obtained from single plot values. The correlations below the diagonal for visual yield score of single crosses show a significantly closer association between autumn and winter, than between either autumn or winter with spring. The high correlation, $+0.96$, between spring visual yield score and green forage yield, suggests that visual yield scores can provide a reliable index of actual forage yields.

DISCUSSION

General combining ability is more important than specific combining ability in synthetic varieties of forage crops. Kalton and Leffel (1955), pointed out that selection for high specific combining ability may lead to a decline in performance in syn. 2 and later generations of a synthetic due to dissipation of non-additive effects. Corkill (1956) concluded, from an investigation of the same plants used in group A plus an additional 3 plants, that for this plant material the most efficient number of unrelated plants to include in a synthetic is 6.

General combining ability measures the variance resulting from deviations of the mean performance of parental plants about the mean of all plants, and is largely attributable to additive effects. On the other hand, specific combining ability measures the variance arising from deviations of individual crosses from the expected performance based upon average parental performance, and is largely due to dominance and epistatic effects. In group A, where the plants had been previously selected for uniform general combining ability, the estimates of specific combining ability were generally greater than those for general combining ability. The reverse was found for group B where the plants had not been previously selected for general combining ability. This is in agreement with the results reported by Sprague and Tatum (1942) in maize and with those of Kalton and Leffel (1955) based upon clones of cocksfoot unselected for general combining ability. The differences between general and specific combining ability found in the two groups of plants studied here are those that would be expected. In plants previously selected for general combining ability dominance and epistatic effects were greater than those for additive effects, largely because the plants remaining from previous elimination trials were more similar than the original unselected plants, differences in additive effects having been largely eliminated. The relative magnitudes of specific combining ability for the two groups of plants, as shown in Table 8, are similar.

Several instances of significant reciprocal differences were found. The significant reciprocal effect observed in group A for the third cut was primarily due to a single parental plant. The forage yield ranged from 8% to 33% less in all four single crosses involving this plant used as the female parent. No explanation can be offered since the plant in question was practically self-sterile. In group B significant reciprocal effects as measured by visual yield scores were observed in the autumn and winter and for interaction with seasons. No consistent pattern, however, was found. The precision of detecting small differences was high since the reciprocals were grown in sub-plots.

In New Zealand, where pastures are utilized for virtually the entire year, it is important to determine the performance of parental plants in all seasons. The results of this study indicate that certain parental plants performed differently in different seasons. In group A, which involved three cuts made during spring, the interaction of plants with cuts was largely caused by a single plant. The performance of this plant was approximately average for the first two cuts and well below average for the third cut. The significant interaction of plants with seasons is shown by the comparison of the rank order given in Table 4. The performances were much more similar between autumn and winter, than between either autumn or winter compared with spring.

The cost of obtaining green forage yields of spaced plants is much greater than that of making visual yield scores. Glenday (unpublished) estimated that 20% more plants would be required for visual yield scores to have the same efficiency as green forage weights. The high correlation between visual yield scores and green forage weight obtained in this investigation shows that visual yield scores made by an experienced individual provide reliable estimates of green forage yield.

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REFERENCES

- BOLTON, J. L. 1948: A Study of Combining Ability in Alfalfa in Relation to Certain Methods of Selection. *Sci. Agric.* 28: 97-126.
- BRIGHAM, R. D.; WILSIE, C. P. 1955: Seed Setting and Vegetative Vigor of Ladino Clover (*Trifolium repens* Leyss) Clones and their Diallel Crosses. *Agron. J.* 47: 125-7.
- CORKILL, L. 1949: Pasture Improvement in New Zealand. *Emp. J. exp. Agric.* 17: 157-69.
- 1956: The Basis of Synthetic Strains of Cross-pollinated Grasses. *Proc. 7th int. Grassl. Congr.* pp. 427-36.
- KALTON, R. R.; LEFFEL, R. C. 1955: Evaluation of Combining Ability in *Dactylis glomerata* L. III. General and Specific Effects. *Agron. J.* 47: 370-3.
- KALTON, R. R.; LEFFEL, R. D.; WASSOM, C. E.; WEISS, M. C. 1955: Evaluation of Combining Ability in *Dactylis glomerata* L. I. Clonal and Outcross Progeny Performance. *Iowa St. Coll. J. Sci.* 29: 631-57.

- KALTON, R. R.; SMITH, A. C.; LEFFEL, R. C. 1952: Parent-Inbred-progeny Relationships of Selected Orchard-grass Clones. *Agron. J.* 44: 481-6.
- KNOWLES, R. P. 1950: Testing for Combining Ability in Brome Grass. *Sci. Agric.* 30: 275-302.
- KEMPTHORNE, O. 1952: "The Design and Analysis of Experiments." John Wiley, New York.
- OLDEMEYER, D. L.; HANSON, A. A. 1955: Evaluation of Combining Ability in Orchard Grass *Dactylis glomerata* L. *Agron. J.* 47: 158-62.
- ROJAS, B. A.; SPRAGUE, C. F. 1952: A Comparison of Variance Components in Corn Yield Trials. III. General and Specific Combining Ability and their Interactions with Locations and Years. *Agron. J.* 44: 462-6.
- SPRAGUE, C. F.; TATUM, L. A. 1942: General vs. Specific Combining Ability in Single Crosses of Corn. *J. Amer. Soc. Agron.* 34: 923-32.

BLOAT IN CATTLE

V. EFFECTS OF INGESTION OF WHALE OIL ON PRODUCTION AND COMPOSITION OF MILK, ON FLAVOUR OF MILK AND BUTTER, AND ON PROPERTIES OF BUTTERFAT

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Summary

Drenching of cows with 300 ml. (276 g.) of whale oil twice daily for 3 days only did not cause any change in milk yield or fat and solids-not-fat contents of the milk; but it caused objectionable "fishy" or "oily" off-flavours in the milk and cream and in the butter made from them. The off-flavours persisted in these products for several days after cessation of drenching. The treatment induced very considerable changes in the properties of the butterfat.

Drenching for 6 days caused similar flavour changes and in addition a 33% reduction in milk yield, a 30% reduction in fat test, a 32% reduction in fat yield, a rise in iodine value from 30 to 60, a rise in refractive index from 1.4530 to 1.4578, a fall in softening point from 33.5 to 27.5°C., a fall in saponification value from 233 to 228, and a fall in Reichert value from 29 to 23.

Emulsification of the whale oil before drenching did not modify the effects.

Measurements of content of unsaturated acids in the butterfat from cows receiving whale oil showed that the major change was an increase in the monoenoic acid content, from 28% to 45%. These results taken in conjunction with the changes in saponification and Reichert values indicate that the monoenoic acid fraction was mainly oleic acid or isomers of oleic acid. There was a small increase in the proportion of conjugated dienoic acids and of non-conjugated tetraenoic acids.

The effects found for whale oil are similar to those recorded by other workers for cod-liver oil and menhaden oil. The effects of fish oils have been attributed to the presence of highly unsaturated C₂₀ and C₂₂ acids in the glycerides of these oils; and it seems probable that the changes caused by ingestion of whale oil have a similar origin.

Because of its marked effects on the flavour of milk, cream, and butter, and on the properties of the butterfat, whale oil is considered to be unsuitable for administration to dairy cows as a treatment or prophylactic for bloat.

INTRODUCTION

In earlier papers in this series it was shown that frothy bloat in dry cattle could be relieved by treatment of the animals with anti-foaming agents, such as vegetable oils, animal oils or fats, and mineral oils (Johns, 1954; Reid and Johns, 1957). These authors found dose rates as low as 50 ml. (46 g.) of oil to be effective for treatment of bloat in stalled animals, but for field use they recommended 120 ml. (114 g.).

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The same agents could be used to prevent bloat by administration as a drench before feeding. Since, however, oily substances are rather quickly lost from the rumen through being passed on down the alimentary tract, simple drenching provides only limited protection unless the oils are administered in large quantities. To obtain 6 hours' protection in stalled cattle, doses in excess of 500 ml. (460 g.) were required. In the field it has been found that protection lasting only 4 hours has been sufficient to control bloat under certain limited circumstances, and drenches of 200–300 ml. (184–276 g.) have been used for this purpose. With administration of the oil as a spray on pasture (providing continuous intake during the period when the cow is feeding) or as an addition to the drinking water, dose rates as low as 90 ml. (83 g.) per cow gave protection for 24 hours, although rates as high as 180 ml. (166 g.) per cow have sometimes been found necessary (Reid, 1955, and in preparation).

Any materials used for either the treatment or the prevention of bloat in dairy cows should not have undesirable effects on milk production, quality, or composition, or on butterfat properties. Such materials, even if used only for treatment, will frequently be administered daily to those animals that are highly susceptible to bloat. If used prophylactically, they will often be given daily to all animals of a herd and to many herds in a district throughout a period during which pastures are dangerous, i.e. possibly for six or seven weeks.

It is already known that the nature and the proportion of fat in a cow's diet have a marked influence on the characteristics of the butterfat; and that some types of oils affect also the milk production and milk composition. Such information as was available on the effects of the oils and fats likely to be used for the treatment and prevention of bloat was however based mainly on experiments in which they were given to cows along with a concentrate feed, and did not cover their ingestion as a drench by pasture-grazing animals. The present series of investigations was designed to provide more complete information on the effects of the various oils and fats on milk production, milk composition, milk and butter flavour, and butterfat characteristics, and to study the influence of different administration regimes on these effects.

Results of trials with heavy liquid paraffin have already been described (McDowall, McGillivray, and Reid, 1957; McGillivray, 1957). The present paper covers drenching trials with crude whale oil, the cheapest of the glyceride oils used by Reid and Johns (1957). In the subsequent paper (McDowall, Reid and Patchell 1957) trials with linseed oil, soya-bean oil, emulsified tallow, and peanut oil given as drenches, and with peanut oil sprayed on to pasture, are reported.

EXPERIMENTAL

The cows were grazed on a mixed ryegrass/white-clover pasture. The milk from each cow was weighed at each milking and samples were taken for organoleptic examination. Composite samples of the night's and following morning's milks were analysed daily for fat and total solids contents. From samples of milk at each milking during the first few days after commencement of treatment, and thereafter from composite night and morning samples, creams were isolated by centrifugal separation. Samples of the creams were held for organoleptic examination.

For Trial I, daily composited samples were pasteurized in a small flash-pasteurizer and churned to butter. The butters were examined by experienced graders, and were then melted down for isolation of butterfat by decantation and filtration. These butterfat samples were used for the investigation on butterfat characteristics. For Trial II, butters were not made. The butterfat samples then were prepared from cream by the method of Dolby (1954).

Iodine values were measured by the Wijs method, refractive index at 40°C. in an Abbé refractometer, softening point by the falling-ball method (Barnicoat, 1944), solidification point (for Trial I only) by the method described for phenol (British Standards Institution, 1955), and saponification and Reichert values by the British Standard Methods (British Standards Institution, 1938).

The whale oil used was a commercial product extracted from whales captured in New Zealand waters. Its iodine value was 137. It was given to the cows as a drench. When given unemulsified it was mixed with an equal volume of water.

There were two separate trials as shown in Table 1.

TABLE 1. DETAILS OF TRIALS WITH WHALE OIL

	Trial I	Trial II
Oil used	whale oil	(a) whale oil (b) emulsified whale oil
Dose rate of oil	300 ml. (276 g.) twice daily	300 ml. twice daily
Number of cows used	2 (unrelated)	4 (2 sets of monozygous twins*)
Date of commencement	24/10/54	23/10/55
Duration (days) of Pre-treatment control period	3	4
Treatment period	3	6
Post-treatment control period	8	9

* Monozygous twins have been shown by McDowall and Patchell (in press) to give butterfats either of very nearly identical characteristics or with fairly consistent differences throughout a lactation. (See also results on treatment with heavy liquid paraffin, McDowall, McGillivray, and Reid (1957)).

The emulsion used in Trial II was prepared in bulk. The emulsifiers employed were the non-ionic surface-active polyethylene glycol derivatives Lubrol W and Lissapol NX (kindly supplied by Imperial Chemical Industries (N.Z.) Ltd.). The oil, water, and emulsifiers were mixed by agitation and then were passed through a homogenizer at a pressure of 1500 lb./sq. in. In the 750-ml. dose of emulsion given at each drenching the constituents were present in the following proportions;

Whale oil	—	300 ml.
Lubrol W	—	12 g.
Lissapol NX	—	12 ml.
Water	—	to 750 ml.

RESULTS

Trial. I. Drenching with 300 ml. (276 g.) Whale Oil Twice Daily for 3 Days

At the time of the experiment the two cows (T9, T90) were yielding respectively 1.3 and 1.9 lb. of butterfat daily. The quantity

TABLE 2. EFFECT OF DRENCHING WITH 300 ML. WHALE OIL TWICE DAILY ON FLAVOUR OF MILK, CREAM, AND BUTTER

Consecutive days* of trial	Description of period	Comments on Flavour					
		Cow T9			Cow T90		
		Milk	Cream	Butter	Milk	Cream	Butter
1,2,4	Control	Sl. cowy or normal	Sl. cowy or normal	—	Sl. cowy or normal	Sl. cowy or normal	—
5 p.m.	300 ml. of whale oil twice daily	No taint	Oily	Oily	No taint	No taint	Cow
a.m.		"	Sl. taint	"	Sl. cowy	Sl. cowy	"
6 p.m.		Def. whale oil	Strong whale oil	Strong whale oil	Sl. taint	No taint	Sl. oily
a.m.		"	"	"	—	—	—
7 p.m.		Coconut flavour	Oily	Strong oily	No taint	Foreign off-flav.	Strong off-flav.
a.m.		Strong whale oil	Strong whale oil	Whale oil	"	"	Oily
8 p.m.	Post-drenching period	Slight whale oil	Oily	Strong oily	Foreign off-flav.	Foreign off-flav.	Oily
a.m.		"	"	"	No taint	"	"
10 p.m.		"	Slight whale oil	Strong whale oil	Foreign off-flav.	"	Cow
a.m.		"	"	"	Almost normal	"	"
12 p.m.		Normal	Normal	No whale oil taint	Slight cowy	Normal, sl. cowy	Cow, no whale oil
a.m.		"	"	"	"	"	"
15 p.m.		Cow	Cow, no whale oil	—	No taint	No taint	—
a.m.		"	"		—	—	—

* Day here represents night's and following morning's milkings.

of whale oil administered was thus approximately equal to the quantity of butterfat in the daily milk production.

Yield and Composition of Milk. Milk yields, percentages of fat and solids-not-fat in the milk, and fat and solids-not-fat yields, were not significantly affected by the treatment.

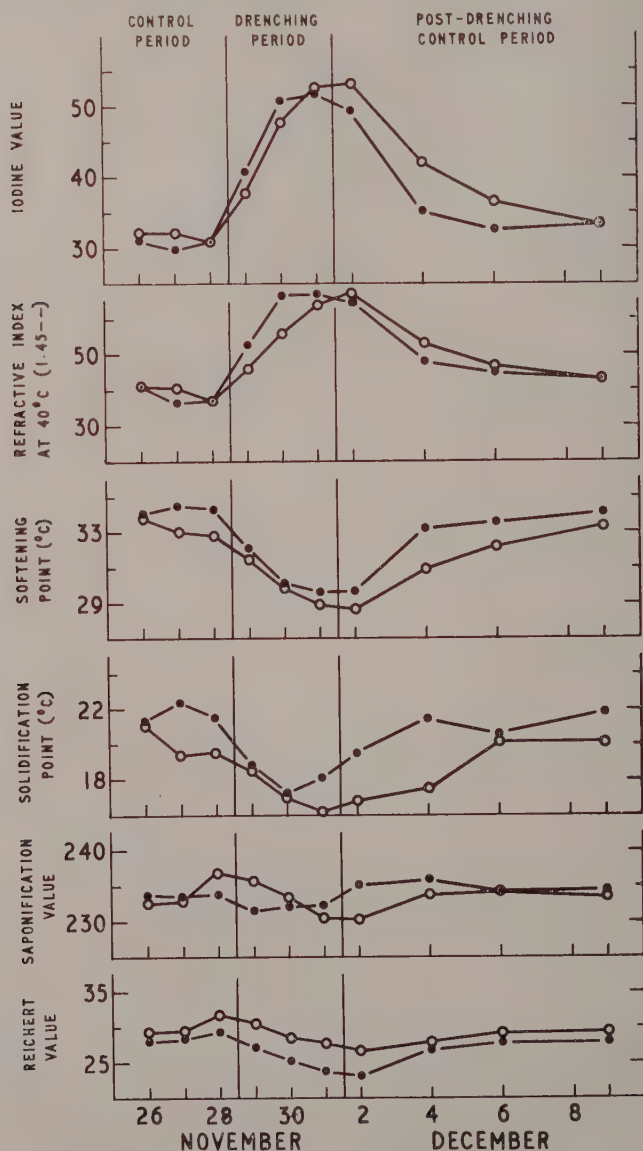


Fig. 1.—Effects of drizzling cows with 300 ml. whale oil twice daily for 3 days on the properties of the butterfat.

—○— Cow T9 —●— Cow T90

Flavour of Milk, Cream, and Butter. The results are given in summary form in Table 2. At the first milking after commencement of drenching, there was an oily off-flavour in the milk and cream from cow T9. At the third milking after drenching, the taint in the milk, cream, and butter from this cow was recognizable as similar to the odour of whale oil, and the butters during this period were reported upon as "inedible". The whale-oil taint persisted in the products from this cow until 2-3 days after cessation of drenching. The milks and creams from cow T90 remained normal for 24 hours after commencement of drenching. Thereafter they had a foreign off-flavour frequently described by the graders as "oily" but not at any time as "whale-oil flavour". The butter from this cow at the end of the drenching period had a strong off-flavour and was almost uneatable. As with cow T9, the flavour of the milk, cream, and butter returned to normal within 2-3 days of cessation of drenching.

Characteristics of the Butterfat. Drenching with whale oil caused an immediate change in the properties of the butterfat (Fig. 1). This applied equally for cow T9, which had yielded milk with a recognizable

TABLE 3. MAXIMUM CHANGES IN BUTTERFAT CHARACTERISTICS AND IN MILK YIELD AND COMPOSITION RESULTING FROM DRENCHING WITH WHALE OIL (Trial I, averages for 2 cows: Trial II, averages for 4 cows)

Details of Drenching	Milk or Butterfat Characteristic	Control Value	Value after Maximum Change	Difference	
				Actual	Percentage
Trial I (300 ml. (276 g.) twice daily for 3 days)	Iodine value	31	52	+21	+68
	Refractive index	1.4539	1.4564	+0.0025	—
	Softening point (°C.)	33.6	29.2	-4.4	-13
	Solidification point (°C.)	20	17	-3.0	-15
	Saponification value	235	232	-3	—
	Reichert value	31	25	-6	-19
Trial II (300 ml. (276 g.) twice daily for 6 days)	Milk yield (lb.)	15	10	-5	-33
	Fat test (%)	6.0	4.2	-1.8	-30
	Fat yield (lb.)	1.30	0.85	-0.45	-35
	Iodine value	30	60	+30	+100
	Refractive index	1.4540	1.4578	+0.0038	—
	Softening point (°C.)	33.5	27.5	-6.0	-18
	Saponification value	233	228	-5	—
	Reichert value	29	23	-6	-21

whale-oil taint (see Table 2), as for T90, the milk from which was tainted but not with a recognizable whale-oil taint. The changes rose to a maximum at the close of the three-day drenching period (see upper section of Table 3). Thereafter there was a gradual return to normal values over a period of 5-6 days. The effect of the 4.4°C. change in softening point of the butterfats was clearly evident in the quality of the butters, which at this period of the trial were very soft and greasy.

Trial II. Comparison of Unemulsified and Emulsified Whale Oils

The very marked effect of whale oil on the characteristics, especially the iodine value and softening point, of the butterfat could have been due to rapid transfer of the oil from the rumen to lower levels in the alimentary tract before enzymatic hydrogenation reactions could occur (Shorland *et al.*, 1955). It appeared possible that the transfer could be retarded by prior emulsification of the whale oil, permitting a more intimate mixing of the oil with the contents of the rumen and allowing a longer time for hydrogenation to take place.

At the time of the trial (November-December 1955) the two sets of monozygous twins used were in the 3rd-4th months of lactation, yielding 0.8-1.5 lb. of butterfat daily. One cow of each twin set was treated with the unemulsified oil and the other cow of the twin set with emulsified oil. Trial II differed from Trial I in that the period of drenching was 6 days instead of 3; and butter was not made from the creams.

Yield and Composition of Milk. Results for milk yield, fat test of milk, and fat yield are given in Fig. 2, as separate averages for the two cows receiving unemulsified whale oil and for the two cows receiving emulsified whale oil. There was no significant difference attributable to emulsification, but for all cows the treatment with whale oil caused a reduction in both milk yield and fat test. This is shown more clearly in Fig. 3, in which the combined averages for the four experimental cows are compared with averages for seven cows of the same herd grazed on the same pasture. There was no change in either milk yield or fat test for this latter group. The average maximum decreases resulting from the drenching with whale oil were between 30% and 35% (see lower section of Table 3). The milk yield remained low for 3 days, and did not return to normal until 6-7 days after cessation of treatment. With both sets of cows (Fig. 2) the fat test reached its minimum at the fourth day after commencement of treatment and was back to normal immediately after drenching was discontinued. Changes in fat yield were of course the direct result of the above changes in milk yield and fat test, but they were smaller than could be expected from a consideration of the maximum percentage reductions in milk yield and fat test because these two maxima did not occur at the same time (see Fig. 3).

There was no change in content of solids-not-fat in the milks. The changes in yield of solids-not-fat therefore followed the changes in yield of milk.

Flavour of Milk, Cream, and Butter. The effect of the drenching with whale oil on the flavour of the milk and cream was less distinct than for cow T9 in Trial I, and it did not show so rapidly. After three

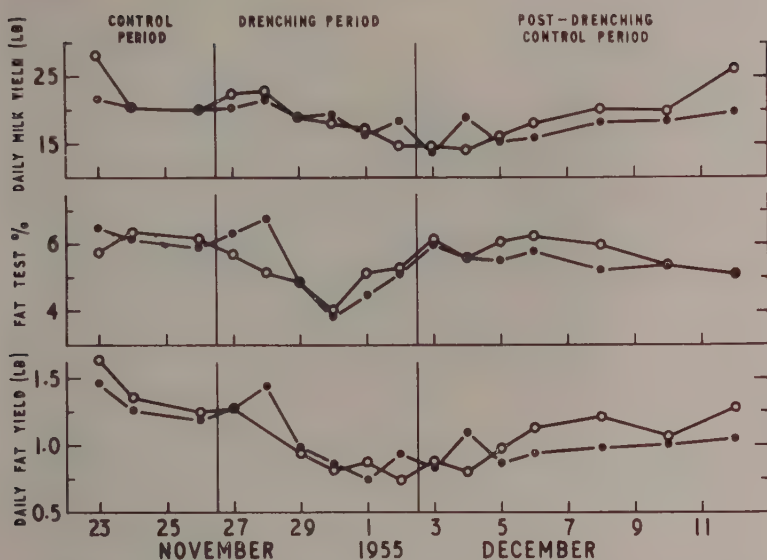


Fig. 2.—Effects of drenching cows with 300 ml. of unemulsified whale oil or with 300 ml. of emulsified whale oil twice daily for 6 days on milk yield, butterfat test, and butterfat yield.

(Each line represents average results for two unrelated cows from two sets of monozygous twins)

— • — • — Unemulsified whale oil — o — o — Emulsified whale oil

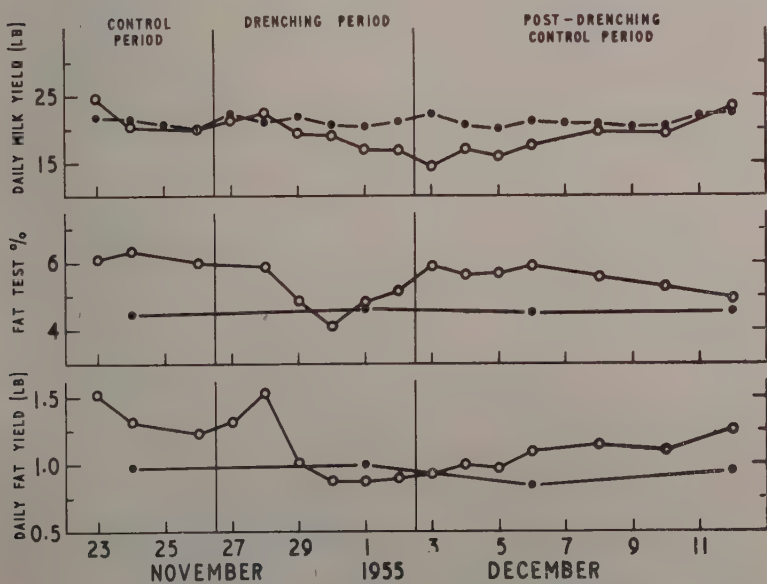


Fig. 3.—Comparison of milk yields, butterfat tests, and butterfat yields for seven untreated cows with those for four cows drenched with 300 ml. of whale oil twice daily for 6 days.

— • — • — Untreated cows — o — o — Treated cows

appearance or in intensity of taint attributable to the difference in physical form of the oil administered.

Characteristics of the Butterfat. The averaged results for the two cows receiving unemulsified whale oil and for the two cows receiving emulsified whale oil are shown in Fig. 4. It is clear that there was no significant difference attributable to emulsification. With all cows the drenching with whale oil caused an immediate rise in iodine value and changes in the other characteristics of the butterfat similar to those reported for Trial I. The major change in the iodine value took place during the first three days of treatment, but there was a further slight rise during the subsequent three days before cessation of treatment. It appears that in the six days the maximum effect on the butterfat had been reached. Possibly because of the extended period of drenching, the effects persisted longer after cessation of treatment than in Trial I.

TABLE 4. RESULTS OF EXAMINATION OF BUTTERFATS BY ALKALI ISOMERIZATION TECHNIQUE

Nature of Estimation	Sample			
	A Pre-treatment control	B Unemulsified oil treatment	C Emulsified oil treatment	D Post-experimental control
Iodine value	30.4	52.5	54.4	34.2
Mono-enoic acids % W/W	27.6	45.6	45.7	31.0
Dienoic acids % W/W				
conjugated	0.7	2.0	2.1	0.9
non-conjugated	0.6	0.6	0.8	0.7
Trienoic acids % W/W				
conjugated	trace	trace	trace	trace
non-conjugated	0.8	0.8	0.6	0.6
Tetraenoic acids % W/W				
conjugated	nil	nil	nil	nil
non-conjugated	0.3	1.3	1.9	0.5
Pentaenoic acids % W/W				
conjugated	nil	nil	nil	nil
non-conjugated*	0.1	0.3	0.4	0.2

* Results probably rather high as information on pure pentaenoic acids was not available to permit calculation of the background absorption.

Even after nine days some slight effect on iodine value and other properties was still evident.

Comparison of the figures in the lower and upper sections of Table 3 shows that with the longer period of treatment in Trial II there was a somewhat greater change in butterfat properties than in Trial I. The iodine value at its maximum was almost double the control value, and the softening point was lowered by almost 6°C.

In both trials there was a greater proportionate change in the iodine values and refractive indices than in the saponification values and Reichert values.

Content of Unsaturated Fatty Acids in the Butterfats as Estimated by the Alkali Isomerization Technique. The butterfat samples used were composites of the residual amounts available (after completion of the above-described analyses), as follows:

- A—from all cows during the pre-treatment control period, Trial II;
- B—from both cows receiving unemulsified whale oil during the experimental period;
- C—from both cows receiving emulsified whale oil; and
- D—from all cows eleven days after cessation of treatment, i.e., in the post-treatment control period.

They were examined by the alkali isomerization technique of Mitchell *et al.* (1943) as modified by McDowell (1953). The results are given in Table 4. It is apparent that emulsification did not alter the effect of the whale-oil drenching on the fatty-acid composition of the butterfat. There were slight but significant increases in the proportion of conjugated dienoic acids and non-conjugated tetraenoic acids, but the changes were not large enough to cause any appreciable alteration of the iodine values and melting points of butterfats. The main change was in the proportion of monoenoic acids, which was increased by 67%.

DISCUSSION

In the present experiments, administration of 300 ml. (276 g.) of whale oil twice daily was followed by the appearance of marked taint in the milk, cream, and butter, and by profound changes in the properties of the butterfat. Several days elapsed after the cessation of the treatments before these effects disappeared completely.

No changes in the milk yield or fat test occurred in Trial I, but in Trial II ingestion of whale oil caused a decrease of approximately 30% in both yield and test. There is no clear explanation for the difference between the two trials in this respect. They were run at the same date in two successive years. The cows were in the same stage of lactation, and the feeding conditions were similar in the two years. None of the treatments had any observed effect on the health of the animals. Since, however, in Trial II neither milk yield nor fat test showed an immediate reaction to the whale-oil drenching and since in both trials the effects on properties of butterfat were similar in character (compare Figs. 1 and 4, and the upper and lower sections of Table 3) it would appear probable that the absence of an effect

on milk yield and fat test in Trial I was due to the brevity of the drenching period.

The increase in the iodine value of the butterfat caused by whale oil ingestion was roughly equivalent to the increase in the monoenoic acid content of the butterfat. The alkali isomerization results do not of themselves show whether this monoenoic acid fraction was wholly or even mainly oleic acid. It seems likely, however, that only a small proportion could have been C_{20} and C_{22} monoenoic acids, since any considerable proportion of these high-molecular-weight acids, coupled with a fall in Reichert value (and therefore in content of low-molecular-weight acids), of the extent recorded in Figs. 1 and 4, would have lowered the saponification value to a much greater extent than was found in the present investigation. Hence if the monoenoic acid fraction were not wholly oleic acid, it probably contained, in addition to oleic acid, one or more isomers of oleic acid. The presence of isomers of oleic acid along with the oleic acid is indicated also by the extent of the lowering of the softening point of the butterfat.

The effects of the whale oil on the butterfat properties were independent of the fluctuations in the daily yield of butterfat. Thus in Trial II the butterfat yields for one cow on the 4th, 5th, and 6th days of drenching were 1.0, 0.53, and 0.88 lb. respectively and the corresponding iodine values were 54.6, 56.0, and 57.2. A study of all the results on this basis has shown that the trend of the curves for changes in all the butterfat properties was not affected by change in the daily yield of butterfat.

The failure of emulsification to modify the effects of whale oil has several possible causes. Emulsification is an uncertain method of delaying the transit of oils through the rumen. On the one hand, it cannot slow up the rate of loss of oil beyond the rate of loss of water from the rumen. On the other hand, if closure of the oesophageal groove were to occur during drenching, part or all of the oil would bypass the rumen completely (see Reid, 1957). Even if dispersion through the rumen contents were to take place initially, the oil may not remain emulsified. In the present experiment, if the emulsion did behave as desired, then the rate of hydrogenation must have been low, or possibly the emulsifying agents in some way protected the oil. There was no way of determining which (if any) of these possibilities was the correct explanation, and it seems that a modified experiment using animals with rumen fistulae would be necessary to provide unequivocal results.

Comparison of Effects of Whale Oil with Effects of Other Oils of Marine Origin

Earlier investigations on the effects of feeding whale oil to milking cows have not shown any marked changes comparable with those recorded above. Thus Sheehy (1933) reported that 10 oz. (280 g.) of sperm-whale oil given daily with the feed for 7 days, and 15 oz. (425 g.) of sperm-whale oil for 5 days, had no effect on milk yield and fat test (see, however, discussion later (p? ?) on composition of sperm-whale oil); and Garner and Sanders (1938) found no effect with 3, 6, and 9 oz. (84, 168 and 252 g.) of whale oil daily. The negative results of Garner and Sanders were possibly due to the dose rates being

much lower than that adopted in the present investigation (although they are not lower than the dose rates for cod-liver oil found to cause depression in fat test (see below)).

Other oils of marine origin, however, have been shown to cause both reduction in milk yield and fat test and profound changes in the characteristics of the butterfat.

Cod-liver Oil. Isaachsen *et al.* (1915) found that when 1.04 kg. cod-liver meal containing 327 g. of cod-liver oil was fed daily, replacing 1.28 kg. of cottonseed meal, there was a fall of 0.35 in the fat test but no change in milk yield. (This change was not shown when the fat was extracted from the meal.) The milk was found to have a slight fatty flavour and the quality of the butter was distinctly inferior, mainly because of its soft oily consistency. No actual flavour of the fish oil could be detected. Isaachsen *et al.* found a rise in iodine value from 33.6 to 41.4 but no change in Reichert value.

Drummond *et al.* (1924) and Channon *et al.* (1924) found no change in milk yield when 227 g. of cod-liver oil was given to a cow along with the concentrate feed, but there was a fall in butterfat test and a corresponding lowering of the butterfat yield. Fishy and other off-flavours were not found in either the milks or the butters prepared from them. The changes in butterfat properties were as shown in the upper section of Table 5. Similar changes have been reported by

TABLE 5. EFFECTS OF FEEDING OF COD-LIVER OIL (Channon *et al.*, 1924) AND MENHADEN OIL (Brown and Sutton, 1931) ON MILK AND BUTTERFAT

Details of Oil Feeding	Characteristic	Control Value	Value after Maximum Change	Difference	
				Actual	Percentage
227 g. cod-liver oil daily for 14 days	Iodine value	26.9	51.4	+24.5	+91
	Refractive index	1.4535	1.4571	+0.0036	—
	Melting point (°C.)	31.5	29	-2.5	-8
	Saponification value	237	221	-16	—
	Reichert value	29.6	24.9	-4.7	-16
1½ lb. (480 g.) menhaden oil daily for 14 days	Daily milk production (lb.)	18	10.4	-7.6	-53
	Daily fat test (%)	3.0	2.1	-0.9	-30
	Daily butterfat yield (lb.)	1.1	0.45	-0.65	-59
	Iodine value	42.4	62.4	+20	+45
	Saponification value	222.3	217.4	-4.9	—
	Reichert value	26.7	19.0	-7.7	-29

Golding (1928), Golding *et al.* (1926, 1928), Mattick (1928), Hart *et al.* (1932), Petersen (1932), Sheehy (1933), Dann *et al.* (1935), McCay and Maynard (1935), Hilditch and Thompson (1936), Garner and Sanders (1938), Moore *et al.* (1945), Fernando *et al.* (1949), and Whiting *et al.* (1949). Moore *et al.* (*loc cit.*) found that the effect of 8 oz. (224 g.) of cod-liver oil daily was smaller when the oil was given in 12 feeds instead of one (the difference was not great except for one of the four cows used).

Golding *et al.* (1926) reported that the butter from cows fed cod-liver oil in increasing amounts from 2 oz. to 8 oz. (56–224 g.) over 10 weeks did not have any fishy flavour or other taint, but Steensberg (1936) found in Danish experiments that the butter had a fishy flavour even with feeding such small quantities as 50 ml. (46 g.) of cod-liver oil per day.

Menhaden (Atlantic sardine) Oil. Feeding of 1½ lb. (480 g.) of menhaden oil to cows daily for 14 days was found by Brown and Sutton (1931) to cause the changes shown in the lower section of Table 5. The return to normal values was still not complete 10 days after cessation of feeding of menhaden oil.

Brown and Sutton did not report any effect of the menhaden oil on the flavour of the milk, cream, and butter, but they noted that the physical properties of the butter made from the milks were quite abnormal—the butter was so soft that after churning it remained in semi-liquid condition at normal temperatures in the laboratory for several days.

Herring Oil. Feeding of 2 oz. (56 g.) of herring oil to goats was found by Graham and Cupps (1938) to lower the weekly milk yield from 25 to 15 litres (40% reduction) and the fat test from 3.4% to 2.4% (30% reduction). The herring oil had an effect on the health of the animals, causing them loss of appetite which of itself could be the cause of at any rate a portion of the reduction in milk yield.

Isaachsen and Ulvesli (1926) reported a fall of 0.11 in fat test when herring meal containing 128 g. of fat replaced peanut cake used in the ration, but this was offset by a rise in the milk yield.

Salmon Oil and Shark-liver Oil. With feeding of salmon oil or shark-liver oil at the rate of 6 oz. (168 g.) per day McCay and Maynard (1935) found some indication of a fall in milk yield and fat test, but the changes were smaller and much less consistent than with cod-liver oil.

In Table 6, typical fatty-acid composition data for some fish oils are compared with the composition of whale oil (after Hilditch 1956). As already noted by Brown and Sutton (1931) most of these oils differ from the oils and fats commonly present in the cows' diet in that they contain a very small proportion of saturated acids and a high proportion of unsaturated C₂₀ and C₂₂ acids.

The reductions in saponification value of butterfats from cows fed whale oil in the present investigation are similar to those reported by other workers for the butterfats from cows receiving cod-liver oil and menhaden oil; and these changes are in line with the findings of Hilditch and Thompson (1936) and Hilditch (1956, p. 133) for butterfat from

TABLE 6. FATTY ACID COMPOSITION OF SOME FISH OILS COMPARED WITH THAT OF WHALE OIL (after Hilditch 1956, pp. 38, 42, 64)

Source of Oil	Cod Liver	Menhaden	Irish Sea Herring	Antarctic Whale	Sperm Whale	
					Head	Blubber
Content of unsaponifiable matter	—	0.6–1.6	0.75	—	—	—
<i>Saturated acids</i>						
C ₁₀	—	—	—	—	3.5	—
C ₁₂	—	—	—	—	16	1
C ₁₄	3.5	6	7.0	9.3	14	5
C ₁₆	10	16	11.7	15.6	8	6.5
C ₁₈	—	1.5	0.8	2.8	2	—
<i>Unsaturated acids</i>						
C ₁₂	—	—	—	—	4 (-2H)	—
C ₁₄	0.5	—	1.2 (-2H)	2.5 (-2H)	14 (-2H)	4 (-2H)
C ₁₆	15.5 (-2H)	15.5 (-2H)	11.8 (-2H)	14.4 (-2.1H)	15 (-2H)	26.5 (-2H)
C ₁₈	31 (-3H)	30 (-4H)	19.6 (-3.5H)	35.2 (-2.5H)	17 (-2H)	37 (-2H)
C ₂₀	31.5 (-6H)	19 (-10H)	25.9 (-5.3H)	13.6 (-7.2H)	6.5 (-2H)	19 (-2.5H)
C ₂₂	14 (-7H)	12 (-10H)	21.6 (-4.4H)	0.1 (-3.8H)	—	1 (-4H)
C ₂₄	—	—	0.1 (-3.8H)	—	—	—

cows fed cod-liver oil (a) that the proportion of butyric and other lower saturated acids in butterfat from cows fed cod-liver oil is approximately halved, and (b), as indicated both by Reichert value estimates and fatty acid analysis, that there is a higher-than-normal proportion of oleic acid and a proportion (5–8%) of high-molecular-weight C₂₀ and C₂₂ acids in the butterfat.

Sperm-whale oil has a fatty-acid composition very different from that of other whale oils (see Table 6) and similar in character to that of vegetable oils and tallow. The report of Sheehy (1933) that 15 oz. (420 g.) of sperm-whale oil daily did not affect either milk yield or fat test thus is not at variance with the conclusion that the effects of cod-liver oil, Antarctic whale oil and other fish oils are due to the presence of C₂₀–C₂₂ unsaturated acids in the glycerides of these latter oils.

It is of interest that feeding of the unsaponifiable matter from cod-liver oil (Golding 1928), or of hydrogenated cod-liver oil (McCay *et al.* 1938), or of hydrogenated herring oil (Graham and Cupps 1938) does not cause the changes in milk yield, fat test, or butterfat characteristics that result from the feeding of raw cod-liver oil and herring oil, and that feeding of the fatty acids obtained from cod-liver oil by gentle hydrolysis resulted in changes similar to those caused by the unhydrolysed oil (Dann *et al.* 1935). Breirem (1949) considers that although feeding stuffs containing marine fats tend to reduce the percentage of fat in the milk this effect will be insignificant if the daily intake of the fats is kept within reasonable limits, e.g. below 100–150 g.

While ingestion of the fish oils is obviously inducing extensive alterations in the butterfat, there is clear evidence that during transfer to the milk the oils undergo marked changes. Thus Dann *et al.* (1935) found that the unsaturated fatty acids of cod-liver oil and of sardine oil had no absorption at 230 $m\mu$, but that those isolated from the butterfat from cows to which these oils had been fed showed strong absorption. The changes in absorption with 4 oz. (112 g.) of sardine oil was of the same order as the change with 4 oz. of cod liver oil. The results given in Table 6 show that the main difference between the butterfat from whale oil and the pre-treatment control butterfat is the rise in the proportion of monoenoic acids from 30 to 45% by weight. It seems therefore that higher unsaturated acids in whale oil, like those in cod-liver oil (Hilditch 1956, p. 133), are changed during the process of milk secretion largely into oleic acid or its isomers.

CONCLUSIONS

Whale oil is obtainable at the present time in New Zealand at less than half the price of vegetable oils. A considerable saving would therefore result if it could be used in place of these oils for the treatment and prevention of bloat.

As a prophylactic for bloat, however, whale oil is of limited value because of its unpalatability to a large proportion of cows (Reid, unpublished results). It is therefore not suitable for administration by spraying on to pastures or by treatment of water supplies, which means that advantage cannot be taken of the lower dose rates used in these methods. Because of the above-described effects on the yield and composition of milk, on the flavour of milk, cream, and butter, and on the consistency of butter, the indications are that it must be regarded as unsuitable for use on dairy cattle at the dose rates employed in prophylactic drenching.

Even if smaller dose rates were used in the treatment of bloated animals, it is probable that the effects reported here would occur in proportion to the dose. This is supported by the finding of Dann *et al.* (1935) that the effects of feeding as little as 4 oz. (113 g.) of cod-liver oil were shown almost immediately. Furthermore, since, as shown above, the taint in the milk and the effects on yield and butterfat characteristics resulting from drenching of cows with whale oil persisted for some days after cessation of treatment, the effects are probably to some extent cumulative.

It is concluded, therefore, that whale oil is unsuitable for field use in the treatment or prevention of bloat in dairy cows.

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REFERENCES

- BARNICOAT, C. R. 1944: *Analyst* 54: 75.
- BREIREM, K. 1949: *Proc. 12th int. Dairy Congr. 1*: 28.
- BRITISH STANDARDS INSTITUTION. 1938: *B.S. 769: 1938*.
- 1955: *B.S. 523: 1955*.
- BROWN, J. B.; SUTTON, T. S. 1931: *J. Dairy Sci.* 14: 125.
- CHANNON, H. J.; DRUMMOND, J. C.; GOLDING, J. 1924: *Analyst* 49: 311.
- DANN, W. J.; MOORE, T.; BOOTH, R. G.; GOLDING, J.; KON, S. K. 1935: *Biochem. J.* 29: 138.
- DOLBY, R. M. 1954: *J. Dairy Res.* 21: 78.
- DRUMMOND, J. C.; CHANNON, H. J.; COWARD, K. H.; GOLDING, J.; MACKINTOSH, J.; ZILVA, S. S. 1924: *J. agric. Sci.* 14: 531.
- FERNANDO, R.; CHENAVER, P.; CORMIER, M. 1949: *Bull. Soc. Chim. biol., Paris* 31 (3/4): 810.
- GARNER, F. H.; SANDERS, H. G. 1938: *J. agric. Sci.* 28: 541.
- GOLDING, J. 1928: *Proc. 8th World's Dairy Congress, London*. p. 44.
- GOLDING, J.; SOAMES, K. M.; ZILVA, S. S. 1926: *Biochem. J.* 20: 1306.
- GOLDING, J.; ZILVA, S. S. 1928: *Biochem. J.* 22: 173.
- GRAHAM, W. R.; CUPPS, P. T. 1938: *J. Dairy Sci.* 21: 45.
- HART, E. B.; HARDLEY, F. B.; HUMPHREY, G. C. 1932: *Wisc. agric. Exp. Sta. Res. Bull.* 116.
- HILDITCH, T. P. 1956: "The Chemical Constitution of Natural Fats". 3rd ed. Chapman Hall, London.
- HILDITCH, T. P.; THOMPSON, H. M. 1936: *Biochem. J.* 30: 677.
- ISAACHSEN, H.; FRIDRICHSEN, L.; WOLD, I. K. 1915: quoted by Breirem (1949).
- ISAACHSEN, H.; ULVESLI, O. 1926: quoted by Breirem (1949).
- JOHNS, A. T. 1954: *N.Z. J. Sci. Tech.* A36: 289.
- MCCAY, C. M.; MAYNARD, L. A. 1935: *J. Biol. Chem.* 109: 29.

- McCAY, C. M.; PAUL, H.; MAYNARD, L. A. 1938: *J. Nutrit.* 15: 367.
- McDOWALL, F. H.; MCGILLIVRAY, W. A.; REID, C. S. W. 1957: *N.Z. J. Sci. Tech.* A38: 839.
- McDOWALL, F. H.; PATCHELL, M. R. (In press): *J. Dairy Res.*
- McDOWALL, F. H.; REID, C. S. W.; PATCHELL, M. R. 1957: *N.Z. J. Sci. Tech.* A38: 1054.
- McDOWELL, A. K. R. 1953: *J. Dairy Res.* 20: 101.
- MCGILLIVRAY, W. A. 1957: *N.Z. J. Sci. Tech.* A38: 878.
- MATTICK, E. C. V. 1928: *Biochem. J.* 22: 144.
- MITCHELL, J. H.; KRAYBILL, H. R.; ZSCHEILE, F. P. 1943: *Industr. Engng. Chem. (Anal.)* 15: 1.
- MOORE, L. A.; HOFFMAN, G. T.; BERRY, M. H. 1945: *J. Dairy Sci.* 28: 161.
- PETERSEN, W. E. 1932: *J. Dairy Sci.* 15: 283.
- REID, C. S. W. 1955: *Proc. 17th Conf. N.Z. Grassl. Ass.* p. 70.
- 1957: *N.Z. J. Sci. Tech.* A38: 825.
- REID, C. S. W.; JOHNS, A. T. 1957: *N.Z. J. Sci. Tech.* A38: 908.
- SHEEHY, E. J. 1933: *J. Dep. Agric. Ireland* 32: 18.
- SHORLAND, F. B.; WEENINK, R. O.; JOHNS, A. T. 1955: *Nature* 175: 1129.
- STEENSBERG, V. 1936: quoted by Breirem (1949).
- WHITING, F.; LOOSLI, J. K.; KRUKOVSKY, V. N.; TURK, K. L. 1949: *J. Dairy Sci.* 32: 133.

BLOAT IN CATTLE

VI. EFFECTS OF INGESTION OF LINSEED OIL, SOYA-BEAN OIL, MIXED BEEF AND MUTTON TALLOW, AND PEANUT OIL ON PRODUCTION AND PROPERTIES OF MILK AND BUTTERFAT

By F. H. McDOWALL¹, C. S. W. REID² and M. R. PATCHELL³*(Received for publication, 24 September 1957)*

Summary

Drenching of cows twice daily for three days with 300 ml. of linseed oil, soya-bean oil, or peanut oil, or with 125 g. of emulsified mixed beef and mutton tallow, did not affect the yield of milk or the percentage fat and solids-not-fat contents of the milk. Drenching with 150 ml. or with 50 ml. of peanut oil twice daily or with 120 ml. once daily for 21 days also had no appreciable effect on the milk yield or composition. Spraying of peanut oil onto pasture and grazing of the pasture to give a dose rate of 300 ml. daily did not affect milk yield or composition over a period of 21 days.

When drenched at the rate of 300 ml. twice daily for 3 days linseed oil gave an oily flavour, reminiscent of linseed oil, in the milk, cream, and butter, soya-bean oil gave a hay-like off-flavour, and peanut oil a slight sweetish foreign flavour considered by the graders to be unobjectionable. Tallow (in the form of an emulsion) at less than half this dose rate had no effect on milk and cream flavours. Drenching with peanut oil at the lower dose rates, and spraying of the oil onto pasture, had no effect on flavour.

At the high dose rates linseed oil, soya-bean oil and peanut oil had immediate effects on the properties of the butterfat. The main changes for all three oils were increases over the three days of up to 10 units in iodine value and corresponding increases in refractive index. Linseed oil caused no appreciable change in softening point or Reichert value, and a fall of 4 units in saponification value; soya-bean oil caused no change in Reichert value but a rise in softening point and a fall of 1.5 units in saponification value; and peanut oil caused a slight rise in the softening point, a fall of 9 units in the saponification value, and a slight fall in the Reichert value. Drenching with 150 ml. peanut oil twice daily caused similar but smaller changes. Drenching with peanut oil at the lower dose rates and spraying of peanut oil on to pasture had no appreciable effect on butterfat properties.

Tallow emulsion drenching at a dose rate of 125 g. of tallow equivalent twice daily had only minor effects on butterfat properties. When the physical difficulties of handling the emulsion are overcome, it should be a suitable material for general commercial use.

It is concluded that in farming practice it would be inadvisable to treat more than a small proportion of the herd at one time with high dose rates of vegetable oils, and that peanut would be the preferable oil. At the lower dose rates recommended for treatment or for prophylaxis by pasture spraying or by addition to the water supply, any of these oils could be safely given to the whole herd over long periods. The final choice of material would then depend on other factors, such as cost.

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INTRODUCTION

Nearly all the reported investigations into the effect of fat in the diet of cows on the yield, composition and flavour of milk and on the properties of the butterfat have been carried out with animals on basal rations of concentrates and roughage. The results do not necessarily apply to the situation where oils and fats are administered to the grazing animal. The present investigations were arranged to determine the effects of these materials when given to cows on ryegrass/clover pasture.

The basis for the use of oils and fats in the treatment and prevention of bloat has been given in other papers of this series (Part I—Johns, (46); III—Reid and Johns, (70); VIII—Reid, (69)).

The effects on milk production and butterfat properties of drenching grazing cows with heavy liquid paraffin B.P. and with crude whale oil have already been reported (52, 54). The present paper describes investigations with a number of other commercially available oils and fats.

EXPERIMENTAL

The materials used were raw linseed, soya-bean, and peanut oils, and an aqueous tallow emulsion. The vegetable oils were all high-grade commercial products, with iodine values 175, 134, and 98, respectively. The tallow was a good quality mixed beef and mutton tallow, iodine value 50. The emulsion, which contained 33% by weight of tallow plus a mixture of fat-based stabilizers (Emulsion A, Reid and Johns, (70)) was kindly prepared and supplied by Messrs. W. & R. Fletcher (N.Z.) Ltd.

Each trial included a pre-treatment and a post-treatment (or recovery) control period. In the first four trials (Nos. III, IV, V, and VI*) the treatment period was 3 days, and in the remaining trials (VIIa, VIIb, and VIII) it was 21 days. In Trials III–VI each of the listed materials in turn was given at a high dose rate, and in Trials VII and VIII peanut oil only was given at three lower dose rates. All materials were given as drenches except in Trial VIII, in which the oil was sprayed on the pasture immediately before grazing. Details of cows, materials, dose rates, and periods of treatment for the trials are given in Table 1.

The various dose rates adopted were based on administration regimes employed in the field. The dose rate in Trials III, IV, and VI, 300 ml. twice daily, is that used in prophylactic drenching. The dose rate for tallow (Trial V) was approximately half that for the three vegetable oils, because of difficulties in the administration of large volumes of emulsion. The dose rate in Trial VIIa, 120 ml., given only once daily, is that recommended for the treatment of bloated animals (Reid and Johns (70)). The dose rate in Trial VIIb, 50 ml. twice daily, is of the order of that used in treatment by addition to drinking water and in pasture spraying. For the pasture-spraying experiment, Trial VIII, a dose rate (300 ml. per cow per 24 hr.) rather higher than those employed in commercial practice (90–180 ml.) was adopted, with the object of producing a maximal effect.

* Trials I and II were the whale oil experiments reported in Part V of this series (McDowall, Patchell, and Reid (54)).

TABLE 1. DETAILS OF TRIALS III-VIII

Trial No.	III	IV	V	VI	VIIa	VIIb	VIII
Oil used	Linseed oil	Soya-bean oil	Tallow emulsion	Peanut oil	Peanut oil	Peanut oil	Peanut oil
Dose rate	300 ml. twice daily	300 ml. twice daily	125 g. tallow emulsified in 600 ml. water twice daily	300 ml. twice daily	120 ml. once daily	50 ml. twice daily	300 ml. daily
Method of administration	drench	drench	drench	drench	drench	drench	sprayed on pasture*
Number and types of cows used	2, (unrelated)	2, (unrelated)	2, (unrelated)	2, (unrelated)	4, (2 sets of monozygous twins)	4, (2 sets of monozygous twins)	24 (12 sets of monozygous twins)
Date of commencement	11/11/54	22/11/54	11/12/54	5/12/54	14/2/55	14/2/55	22/9/55
<i>Duration (days) of</i>							
Pretreatment control period	3	3	2	2	2	2	12
Treatment period	3	3	3	3	21	21	21
Post-treatment period	6	8	6	7	13	13	9

*In Trial VIII one member of a set of monozygous twins was drenched twice daily with 150 ml. of peanut oil—see later under "Results".

Collection of data and methods of sampling and analysis were as described for the whale-oil trials (McDowall, Patchell, and Reid (54)).

RESULTS

Drenching with Linseed Oil, 300 ml. Twice Daily (Trial III)

Yield and Composition of Milk. Drenching with linseed oil for 3 days did not have any appreciable effect on the yield of milk, or any immediate effect on the fat and solids-not-fat contents of the milk, or on the yields of fat and solids-not-fat (see, however, Table 3 and Discussion on possible later effects on fat test).

Flavour of Milk, Cream, and Butter. There was no appreciable effect on the flavour of these products during the first two days of treatment. On the third day the milk and cream from one of the cows had a sweetish foreign flavour and the butters from both cows had a taint reminiscent of the flavour of linseed oil. The foreign flavour was

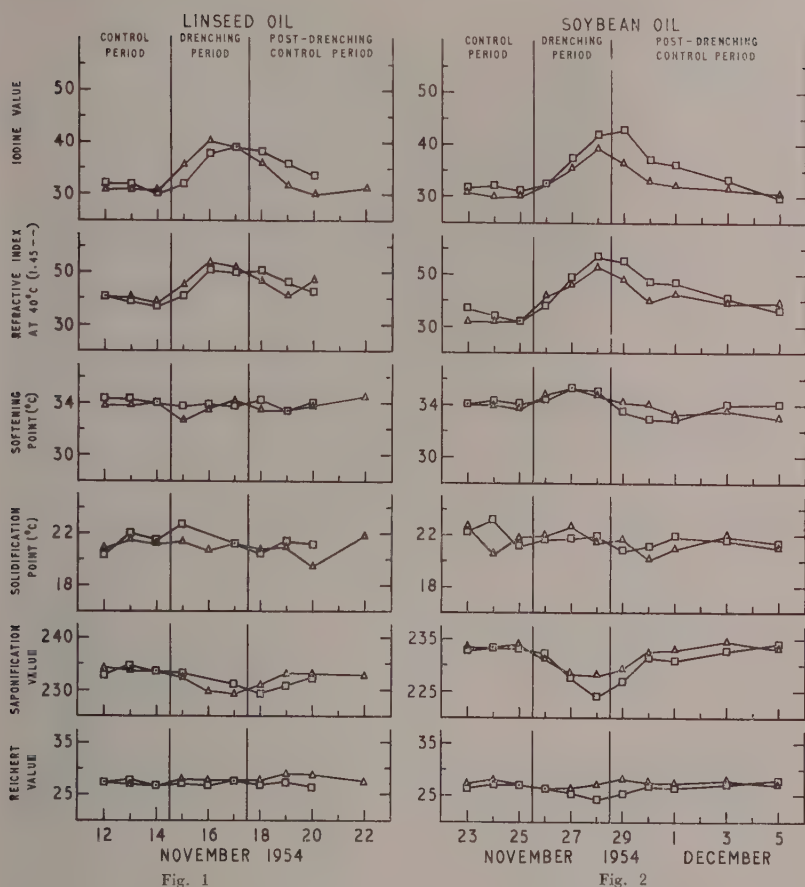


Fig. 1.—Effect of drenching two unrelated cows with 300 ml. of linseed oil twice daily for 3 days on properties of the butterfat.

Fig. 2.—Effects of drenching two unrelated cows with 300 ml. of soybean oil twice daily for 3 days on properties of the butterfat.

observable in the milk and cream for several days after cessation of treatment, but it was not detectable in the butter. The foreign flavours noted in the milks and creams were not objectionable; but the graders reported that the linseed-oil taint in the butter, when it could be detected as such, was strong enough to lower the quality of the butter to second grade.

Characteristics of the Butterfat. The results are shown in Fig. 1. Following commencement of drenching there was an almost immediate rise in iodine value of the butterfat, reaching a maximum rise of 9–10 units in three days. There were corresponding changes in refractive index. After cessation of drenching there was a gradual return to normal, over a period of 3–4 days. These changes were not accompanied by any alteration in softening point but there was a fall of about 1°C.

TABLE 2. EFFECT OF DRENCHING WITH 300 ml. OF LINSEED, SOYA-BEAN AND PEANUT OILS, TWICE DAILY FOR THREE DAYS, ON BUTTERFAT CHARACTERISTICS

Oil Drenched	Butterfat Characteristics	Control Value	Value after Maximum Change	Difference	
				Actual	Percentage
Linseed (Iodine value, 175)	Iodine value	30.0	39.5	+9.5	+32
	Refractive index	1.4539	1.4552	+0.0013	—
	Softening point (°C.)	34.0	34.0	0	0
	Solidification point (°C.)	21.5	20.5	-1.0	-5
	Saponification value	234	230	-4	—
	Reichert value	26.5	27.5	+1.0	+4
Soya-bean (Iodine value, 134)	Iodine value	30.5	40.5	+10	+32
	Refractive index	1.4533	1.4555	+0.0022	—
	Softening point (°C.)	34.0	35.2	+1.2	+3.5
	Solidification point (°C.)	21.0	19.0	-2.0	-9.5
	Saponification value	233	226	-7	—
	Reichert value	27.0	26.0	-1.0	-3.7
Peanut (Iodine value, 98)	Iodine value	31	40	+9	+29
	Refractive index	1.4541	1.4556	+0.0015	—
	Softening point (°C.)	34.6	35.4	+0.8	+2.3
	Solidification point (°C.)	21.6	24.1	+2.5	+11.6
	Saponification value	234.5	225.5	-9.0	—
	Reichert value	29	26.5	-2.5	-8.6

in solidification point. The saponification value fell as a result of the treatment, but there was no significant change in Reichert value. The averages prior to drenching and at the period of maximum change are given in Table 2.

Drenching with Soya-bean Oil, 300 ml. Twice Daily (Trial IV)

Yield and Composition of Milk. There was no appreciable effect on the yields of milk, fat, and solids-not-fat, nor on the fat and solids-not-fat contents of the milks (see, however, Table 3 and Discussion on possible later effects on fat test).

Flavour of Milk, Cream, and Butter. In the creams from both cows at the evening milking on the first day of drenching a hay-like flavour was evident, and during the following two days of drenching this became observable also in the milks and butters. The taint was present for 3 days after cessation of treatment, but during this time its intensity gradually diminished. The off-flavour, though foreign to normal New Zealand milk, cream, and butter, was not considered by the graders to be very objectionable, and the butters were reported on as being of acceptable table quality. In those instances where the hay-like off-flavour was not definitely discernible, the milks and creams were characterised by the absence of the normal nutty flavour.

Butterfat Characteristics. During the three days of drenching with soya-bean oil, the iodine value rose steadily (see Fig. 2 and Table 2).

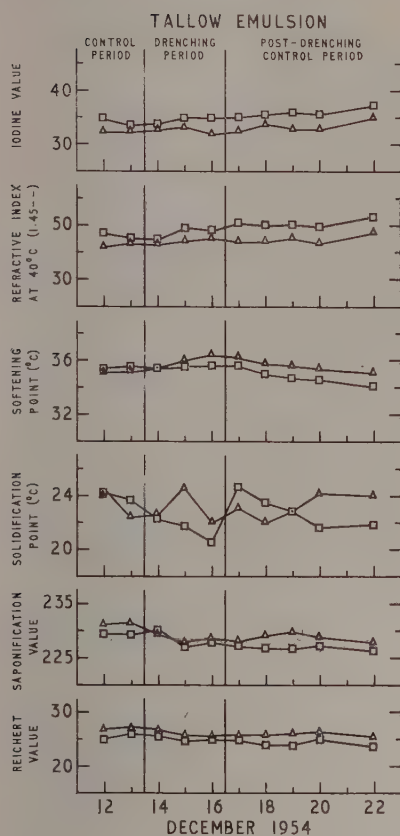


Fig. 3

Fig. 3.—Effects of drenching two unrelated cows with 150 ml. of tallow in an emulsion with water twice daily for 3 days on properties of the butterfat.

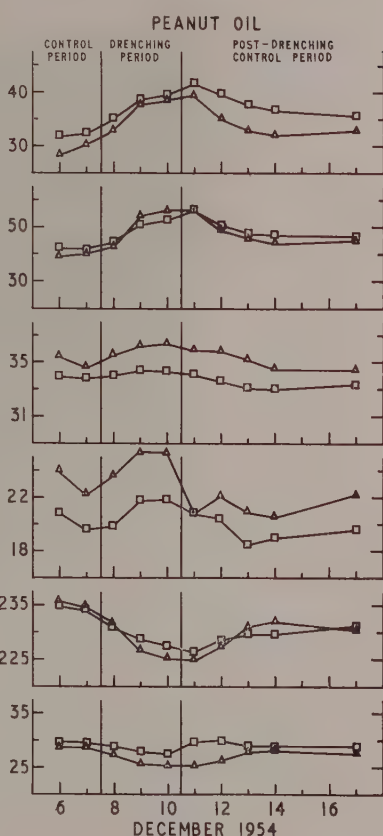


Fig. 4

Fig. 4.—Effects of drenching two unrelated cows with 300 ml. of peanut oil twice daily for 3 days on properties of the butterfat.

The total rise was 9–11 units. There was a corresponding rise in refractive index. After cessation of drenching, the values gradually returned to normal over a period of 6–7 days. There was a rise of about 1°C. in softening point, followed, during the post-drenching period, by a fall to slightly below the control value. The changes in solidification point were not significant. Saponification values fell by 5–8 units during the drenching period, and returned to normal over several days in the post-drenching period. Reichert values were not significantly affected.

Drenching With 125 g. Tallow as Emulsion Twice Daily (Trial V)

Yield and Composition of Milk, and Flavour of Milk and Cream.

There was no effect on yield, composition or flavour.

Butterfat Characteristics. The results are shown in Fig. 3. There was a slight fall in saponification value and Reichert value and a possibly significant slight rise in iodine value.

Drenching with 300 ml. Peanut Oil Twice Daily (Trial VI)

Yield and Composition of Milk. As with the other oils used there was during the drenching period no effect of any practical importance (see, however, Table 3 and Discussion on possible later effects on fat test).

Flavour of Milk, Cream, and Butter. Towards the end of the drenching period and for two days afterwards there were occasional observations of a slight sweetish taste in the milk and cream, but not in the butter. The off-flavour was not sufficiently strong to be commercially significant.

Butterfat Characteristics. The results are shown in Fig. 4 and Table 2. During the three-day drenching period there was a rise of 9 units in iodine value. Following cessation of drenching there was a gradual fall, but even after seven days the iodine value had not returned completely to normal. For one of the two cows there was a slight fall in softening point of the butterfat and for the other cow there was a rise of 1.5°C. in the softening point and a somewhat similar rise in solidification point, despite the accompanying rise of about 8 units in iodine value.

Peanut-oil drenching had a marked effect on the saponification value of the butterfat, lowering it from 235 to 225-7, i.e., by 8-10 units, and there was a fall of 2-3 units in Reichert value.

Combined Milk Yield and Composition Results, Trials III, IV, VI

In Table 3 the milk yield and composition results for the three oils of somewhat similar character, viz., linseed, soya-bean, and peanut, dosed at 300 ml. twice daily have been grouped together, as averages for the three oils for the pre-treatment control period of 2-3 days, for the drenching period of 3 days, for the first three days of post-treatment control, and for the following 2-4 days.

With all these oils there was a slight increase in yield of milk during the drenching period. The fat tests in the two post-drenching periods were appreciably lowered. The solids-not-fat content of the milk was not affected by the drenching treatment.

Drenching with Peanut Oil at Lower Dose Rates (Trial VII)

Trial VIIa. Two cows were drenched with peanut oil at a dose rate of 120 ml. once daily in the evening and their monozygous twin mates were left untreated.

Trial VIIb. Two cows were drenched with 50 ml. of the oil twice daily and their twin mates as before were left untreated.

The two trials were run simultaneously during February and March, i.e., when the cows were in the later stages of lactation and when therefore some changes in butterfat characteristics with progress of the season would be expected (Cox and McDowall (13)). Milk analyses and organoleptic examinations of the milks and creams were done on the night's and morning's composite samples from the delivery from each

TABLE 3. AVERAGE YIELDS, FAT TEST, AND SOLIDS-NOT-FAT CONTENTS OF MILK FROM COWS IN TRIALS III, IV, AND VI

	Oil Drenched	Pre- treatment Control Period	Drenching Period	Post-drenching Control Periods	
				I	II
Daily milk yield (lb.)	Linseed	33.21	33.37	32.12	30.65
	Soya-bean	31.94	32.35	33.55	32.45
	Peanut	23.80	25.00	22.27	21.80
	Average	29.65	30.24	29.31	28.30
Daily fat test (%)	Linseed	4.99	5.31	4.40	3.98
	Soya-bean	4.56	4.69	4.70	4.17
	Peanut	5.73	5.79	5.23	4.89
	Average	5.09	5.26	4.78	4.35
Daily solids-not- fat content (%)	Linseed	9.01	9.17	8.92	8.96
	Soya-bean	8.87	8.84	9.14	8.87
	Peanut	9.38	9.24	9.19	9.15
	Average	9.08	9.08	9.06	8.99

cow twice in the pre-treatment period and then twice weekly throughout. Butterfats from each cow's milk were isolated twice weekly for chemical analysis.

Yield and Composition of Milk. Since there was no indication of any difference due to the different dosing schedules, the results have been grouped as averages for all four cows receiving peanut oil and for their four twin mates as controls (see Table 4). The change in average daily milk yield during progress of the trial was for all practical purposes the same for both control and treated cows, giving a substantially constant yield difference. Fat and solids-not-fat contents of the milk were not affected by the drenching with peanut oil.

Flavour. There was no evidence of any foreign flavour in the milks or creams from any one of the treated cows throughout the period of treatment.

Butterfat Properties. In Trial VIIa (see Fig. 5) there was an increase in divergence between the control and the experimental groups, in the averages for iodine value, refractive index, and saponification value, whereas the relationship between the two lines for softening point and for Reichert values remained consistent throughout. In Trial VIIb (see Fig. 6) there were indications of similar but smaller divergences after the first week of treatment. These divergences are in the direction that would be expected from the results of the high-dose-rate drenching with peanut oil in Trial VI (Fig. 4). Because of the small scale, both of the experiment and of the differences observed, no definite conclusion

TABLE 4. AVERAGES FOR MILK YIELD AND COMPOSITION FOR FOUR COWS DRENCHED WITH PEANUT OIL AT LOW DOSE RATES COMPARED WITH AVERAGES FOR THEIR UNTREATED MONOZYGOUS TWIN MATES

		Pre-treatment	Drenching				Post-treatment
Period No.		1	2	3	4	5	6
Average daily milk yield (lb.)	Control	16.62	14.44	14.48	14.68	13.63	15.89
	Treated	14.00	12.24	11.91	12.09	11.02	13.05
	Difference	-2.68	-2.18	-2.57	-2.59	-2.61	-2.89
Fat test (%)	Control	5.25	5.56	5.28	5.24	5.62	5.43
	Treated	5.67	5.74	5.44	5.44	5.62	5.64
	Difference	+0.37	+0.18	+0.16	+0.20	±0	+0.21
Solids-not-fat content (%)	Control	8.81	8.70	8.75	8.71	8.66	8.83
	Treated	8.91	8.74	8.78	8.73	8.74	8.84
	Difference	+0.10	+0.04	+0.03	+0.02	+0.08	+0.01

can be drawn. The results presented in Figs. 5 and 6, however, taken in conjunction with those in Fig. 4, are interpreted as at least indicating that there was some effect of the longer period of drenching at the lower dose rates.

Spraying of Peanut Oil on Pastures (Trial VIII)

The spray was prepared each day immediately before use. The required quantity of oil to give a dose rate of 300 ml. per cow per day (3.3 litres) was emulsified with water in a high-speed mixer, with 50 ml. of Lissapol NX* as an emulsifying agent.

The pastures were grass-dominant rye-grass/white-clover mixtures, 9-12 inches high. Each paddock was divided into two parts by means of a double-strand electric fence, so that the control cows could be grazed alongside the experimental cows on the other side of the dividing fence. Each afternoon, at 4 p.m., the calculated ration of pasture for the experimental cows for the following 24 hours was sprayed with the emulsion as evenly as possible, using a knapsack sprayer with a hand wand and two Vermorel-pattern horticultural nozzles.

Both groups of cows, control and experimental, were given their respective rations in two breaks, one after each milking. The animals

* Lissapol NX is a non-ionic surface-active agent, a polyethylene glycol derivative. The material used was kindly supplied by the distributors, Imperial Chemical Industries (N.Z.) Ltd.

TABLE 5. EFFECT OF GRAZING OF COWS ON PASTURES SPRAYED WITH PEANUT OIL ON MILK YIELD AND COMPOSITION

		Control		Experimental			Control	
Period No.		1	2	3	4	5	6	7
Days		6	6	7	7	7	5	4
Daily milk yield (lb.)	Control	27.0	27.6	27.1	25.6	24.1	24.2	25.0
	Treated	23.9	24.1	23.1	22.7	21.9	21.8	22.4
	Difference	-3.1	-3.5	-4.0	-2.9	-2.2	-2.4	-2.6
Fat test (%)	Control	4.94	5.01	5.01	4.98	5.02	5.32	4.95
	Treated	5.13	4.91	5.00	4.99	5.11	5.35	4.96
	Difference	+0.19	-0.10	-0.01	+0.01	+0.09	+0.03	+0.01
Daily fat yield (lb.)	Control	1.35	1.37	1.35	1.28	1.17	1.24	1.23
	Treated	1.23	1.18	1.13	1.16	1.08	1.15	1.12
	Difference	-0.12	-0.19	-0.22	-0.12	-0.09	-0.09	-0.11
Solids-not-fat (%)	Control	9.33	9.37	9.36	9.26	9.29	9.19	9.22
	Treated	9.30	9.43	9.40	9.32	9.32	9.20	9.29
	Difference	-0.03	+0.06	+0.04	+0.06	+0.03	+0.01	+0.07
Daily solids-not-fat yield (lb.)	Control	2.56	2.59	2.60	2.41	2.22	2.20	2.33
	Treated	2.22	2.27	2.16	2.12	1.98	1.99	2.15
	Difference	-0.34	-0.32	-0.44	-0.29	-0.24	-0.21	-0.16

Flavour of Milk and Cream. The milks and creams from the four treatment cows sampled individually and those from the seven treatment cows sampled as a composite were normal throughout in comparison with the corresponding samples from the cows grazing on untreated pastures. The milks and creams from the cow drenched with 150 ml. of peanut oil twice daily were free from taint.

Butterfat Properties. The averages for Group A are shown in the top sections of the graphs for each characteristic in Fig. 7, and those for Group B in the bottom sections of the graphs. There is no indication that the ingestion of 300 ml. peanut oil daily along with the pasture caused any appreciable change in the properties of the butterfat.

The results for the two cows in Group C are shown in Table 6 as differences between the values for the treated and control cows. The iodine value of the butterfat from the treated cow was increased, the difference reaching a maximum of about 5 units during the first week,

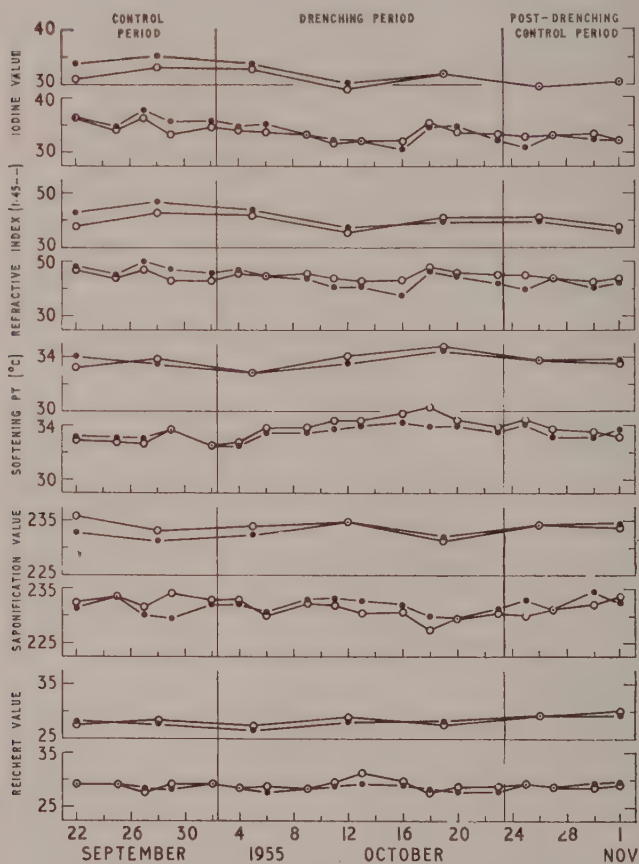


Fig. 7.—Average results for butterfats from four cows sampled individually (top graph in each section), and results for composite butterfats from seven other cows (bottom graphs in each section) grazed on pasture sprayed with peanut oil to give a dose rate of 150 ml. twice daily, compared with results for butterfats from their monozygous twin mates grazed on similar untreated pasture.

— . — . Untreated pasture - - - - - Treated pasture

and thereafter remaining steady until the close of the treatment period. The changes in refractive index were similar in trend. Softening point was not changed. Saponification value was reduced by 5-6 units, and Reichert value by up to 2.5 units.

These definite effects on butterfat properties resulting from drenching with 150 ml. of peanut oil twice daily were similar in character although smaller than those resulting from drenching with 300 ml. twice daily, but were in marked contrast to the minor effects of ingestion of 300 ml. daily of the oil sprayed on to pasture.

TABLE 6. BUTTERFAT FROM COW DRENCHED WITH 150 ml. PEANUT OIL TWICE DAILY OVER 3 WEEKS COMPARED WITH BUTTERFAT FROM UNTREATED MONOZYGOUS TWIN MATE

Sampling Date	Period	Differences* between Results for Treated and Control Cows				
		Iodine Value	n_{40}^D	Softening Point	Saponification Point	Reichert Value
22-23/9/55	Control	0	+0.0001	+0.3	-1.4	-0.8
28-29/9/55	"	+0.4	+0.0002	+0.5	+0.6	0
5-6/10/55	Drenching†	+2.5	+0.0004	+1.0	-3.1	0
12-13/10/55	"	+4.6	+0.0011	+0.3	-5.7	-1.4
19-20/10/55	"	+5.2	+0.0009	+0.4	-5.8	-2.5
26-27/10/55	Immediate post-drenching	+5.1	+0.0008	+0.1	-5.1	-1.6

* Positive difference indicates higher value for butterfat from the treated cow.

† Drenching commenced 4/9/56, terminated 25/10/56.

DISCUSSION

In stall feeding, where the cows are fed on basal rations with the experimental diet either added to or substituted for a portion of the ration, there is some control of the total intake, and if all the ration is consumed the plane of nutrition can be kept constant or changed as required. When the cows are at pasture absolute control of the amount actually consumed by each cow is not possible. In the drenching trials described above, the cows were free to consume pasture *ad libitum*. In Trial VIII, in which the peanut oil was sprayed on the pasture, the break-grazing system introduced some degree of rationing of the pasture, but still gave no control of the amount of pasture consumed by the individual cows. Although this lack of control of total intake introduces an element of uncertainty and of possible variation into the investigation, the conditions are representative of those which can be expected to prevail in general use of the oils for bloat treatment or control in this country. To the extent, therefore, that the cows and pastures used were truly representative of cows and pastures under conditions of commercial milk production, the results can be accepted as valid and applicable in New Zealand farming practice.

Yield and Composition of Milk

The evidence available on the influence of high content of fats and oils (other than marine oils (54)) in the diet of cows on yield and composition of milk is somewhat conflicting (see reviews, (24, 45)). There are a number of reports of increase in milk yield and fat test resulting from the feeding of high-fat rations to cows (1, 26, 59) but there are also many reports of investigations in which such changes have

not occurred (50, 62, 72, 73, 81, 84, 88). There is evidence that the effect of the fat given varies with change in the nature of the other constituents of the ration, e.g., in the amount and type of roughage accompanying the fat (5, 19, 23, 24, p. 208, 49, 79, 83), and with variation in the physical condition of the oil at time of feeding. Fats and oils distributed throughout the ration appear to have less effect than fats given in concentrated form (7, 85).

The effect of the oils on the cow's digestive system may also be of importance. Leroy (47) refers to development of digestive upsets from heavy feeding of oils, and Buschmann (10) concluded that feeding of cows with more than 2 lb. of fat daily usually resulted in digestive troubles; but Allen (1), in his extensive experiments, found no evidence of digestive upsets from the addition of 1.25 lb. (583 g.) of fat to the daily ration of cows. Digestive upsets generally lead to reduction in milk yield. In the present investigation, with administration of 600 ml. of oil daily in the form of drenches, there was no outward evidence of any digestive troubles, and these observations are supported by the absence of the reduction in milk yield which would be expected if the cows had been upset by the oil given.

Oils and fats of marine origin are known to cause variations in both milk yield and fat test (see review, (54)). This has been attributed to the presence in these products of an appreciable proportion of C_{20} - C_{22} highly unsaturated acids. In fatty materials of the type used in the present investigation acids higher than C_{18} are present only in peanut oil, which may contain 5-8% of the C_{22} saturated arachidic acid (see Table 8). Concentrates containing linseed oil, soya-bean oil, and peanut oil are in general use for the sustenance of milking cows, and animal fats, such as lard and tallow, have been recommended for the same purpose (42).

Sheehy (72, 73) reported no change in milk yield but a lowering of fat test when 15 oz. (420 g.) of *linseed oil* were fed daily to cows for 14 days. Following cessation of treatment there was a residual effect lasting for 6-8 days. Smaller quantities of linseed oil or larger quantities, 24 and 30 oz. (672 and 840 g.) for a shorter time (5 days) had no effect. Allen (1) found no change in milk production but an increase in fat test and in butterfat production from the feeding of up to 1.25 lb. (583 g.) of linseed oil per 12 lb. of grain. Garner and Sanders (26) found no effect from the feeding of 9 oz. (252 g.) of linseed oil over a five-day period.

With *soya-bean oil* Sheehy (72, 73), feeding at the rate of 10 oz. (280 g.) daily for 9 days, and Garner and Sanders (26), feeding at 9 oz. (252 g.) daily for 5 days, found no effect on milk yield or fat test; but positive effects on milk yield or fat test have been reported by a number of other workers (4, 7, 41, 85). Bainter *et al.* (4) in their experiments with soya-bean feeding pointed out that the increase in milk yield which they obtained was small in relation to the increase in intake of nutrients with the beans.

With *animal fat* Sheehy (72) feeding $\frac{1}{2}$ lb. (227 g.) of beef suet daily, Horton *et al.* (42) feeding 4-8.5% of beef tallow, and Harland *et al.* (30) feeding a concentrate ration containing 7% of tallow, found no effect on milk yield; but Allen (1), feeding 1 lb. (454 g.) of tallow

per 10 lb. of grain, and Allen and Fitch (2), replacing 3.4 lb. of corn starch in the ration with 1.5 lb. (681 g.) of lard, found increases in both milk yield and fat test.

With *peanut oil* Sheehy, feeding 8 oz. (227 g.) daily for 18 days, reported no effect on milk yield and fat test, but Allen (1), feeding 1.25 lb. (583 g.) of peanut oil as an addition to the normal ration, found increases in milk yield and fat test similar to those recorded for linseed oil and soya-bean oil.

The results of Trials III–VI in the present investigation indicate that with cows at pasture a three-day period of treatment with any of the oils used, even at the high dose rate of 300 ml. twice daily, gave only a slight increase in milk yield and no change in fat test during the drenching period. After cessation of drenching with all these vegetable oils, however, there was a fall in fat test of the milks (see Table 3). Although the range of results available is not sufficiently extensive to justify the drawing of any firm conclusions, it is of interest that Allen and Fitch (2) and Nevens and Tracy (64) found some evidence of a residual depressing effect after cessation of soya-bean oil feeding. Allen (1), on the other hand, states that following the feeding of fats there was in his experiments no residual effect on the milk yield and fat test.

Flavour of Milk, Cream, and Butter

The results of studies on effects of an oil drench on the flavour of milk can be expected to vary with variation in (a) time between ingestion and milking, (b) quality of oil or fat administered, (c) nature and quality of other constituents of the diet, and (d) cow individuality (see review, 51, p. 135).

In the literature there are frequent references to the absence of adverse effects on flavour of milk when products containing the oils used in the present investigation were fed to cows, e.g., linseed oil (11), soya-bean oil (4, 11, 25, 48, 58, 64, 86), tallow (42) and peanut oil (18). Horn and Muhl (41), however, found a soya-bean taste in butter when soya beans comprised 35% of the ration of concentrates but no effect when the 35% supplement was solvent-extracted soya beans, thus indicating that the source of the off-flavour was either the oil or substances dissolved in the oil; and workers at S. Carolina Experiment Station (78) reported that when ground soya beans made up one-half of the cows' ration the butter obtained was of low grading owing to oily flavour.

The minimum effect would be expected when the feed or drench is given immediately after milking (51, p. 135). In the present investigation these conditions applied for all the drenching trials (I–VII). Although in Trial VIII the cows were turned on to the oil-sprayed pastures immediately after milking, they remained on the pastures throughout the interval between milkings. As outlined above, definite positive effects on flavour were obtained with drenching of 300 ml. of linseed and soya-bean oils twice daily, slight effects were obtained with drenching of 300 ml. of peanut oil twice daily, and no effects were obtained from the drenching of 125 g. of tallow twice daily, or from the drenching of 150 ml. or 50 ml. of peanut oil twice daily, or of 120 ml. once daily, or from the spraying of peanut oil on to pasture to give a dose rate of 300 ml. daily. The off-flavour from the drenching with

peanut oil was only slight, but that present in the products from cows drenched with 300 ml. of linseed and soya-bean oils was sufficiently strong to be easily recognised.

Properties of Butterfat

The nature and extent of the influence of fat in a cow's ration on the properties of the butterfat can be modified by a number of factors:

(a) *Condition of cow.* Since the depot fats are in a constant state of flux (74), the condition of the cow can affect the proportion of fat passing into and out of the depots in relation to the amount of fat in the diet (1). Jarl (44) found a correlation between negative weight changes of a cow and changes in iodine value of the butterfat, but not between positive weight changes and change in iodine value.

(b) *Individuality of cow.* Character of butterfat from cows on the same ration varies with breed of cow (57), and among cows of the same breed, with cow individuality. Also different cows react differently to the same change in ration.

(c) *Plane of nutrition.* Cows on a low plane of nutrition draw more heavily on their depot fats than cows on a high plane of nutrition (1, 44). The effect on butterfat is very marked during inanition (20, 57, 76).

(d) *Character of the butterfat produced on the basal ration.* If a cow is already producing butterfat of high iodine value the effect of addition to the diet of an oil likely to cause a rise in iodine value is smaller than when the iodine value of the butterfat during the pre-treatment period is low. Nevens and Tracy (64) and Hilditch and Jasperson (34) found little effect on iodine value from the feeding of soya-bean and peanut oil, respectively, but the iodine value of the butterfat in the basal diet was already 40.

(e) *Amount and character of fat in the basal ration.* Since the added fat is diluted by the fat in the basal ration, its effect can be expected to vary with variation in the amount and character of the fat already present in the diet (3). But butterfat is produced also from protein and carbohydrate in the ration, and the fat so produced is of low iodine value and high melting point. The quality of the control butterfat thus is not dependent solely on the character of the fat in the basal ration.

(f) *Physical condition of the fat added.* The effect of oil or fat on butterfat properties appears to be dependent to some extent on the form in which the fat is added to the ration. Thus feeding of soya-bean meal plus the extracted oil is reported to cause a greater change in the butterfat than feeding of the whole soya bean (7, 85). Johansson and Claesson (45) state that "the effect of oils on the milk fat may be modified by feeding them in whole grain or meal, which will influence the rate of digestion and absorption, and therefore of desaturation".

(g) *Nature of the basal ration.* Fats taken in the diet are very appreciably modified by hydrogenation reactions in the rumen (38, 75). The extent of change of dietary fat before it passes to the lower alimentary canal thus may depend on the conditions already obtaining in the rumen as the result of ingestion of the basal diet (5, 20, 65).

Despite the operation of the above factors, there is a fair measure of agreement as to the influence of added fats in the ration on the properties of butterfat. While the generalization of Jarl (44) that there is no correlation between iodine value of feed fat and iodine value of butterfat is scarcely justified by the results of the mass of experimental work reported in the literature, the assumption (57, 71, 80, 84) that there is a direct proportionality between these values is also an oversimplification of the position. Usually the butterfat is modified in the direction in which the added fat differs from the fat in the basal ration (see discussion on factors (d) and (e) above). This latter generalization, however, cannot be applied in detail. Thus feeding of hydrogenated soya-bean oil was found by Brown *et al.* (8) to increase the degree of unsaturation of the butterfat; feeding of partly hydrogenated peanut oil, iodine value 45, was found by Hilditch and Jasperson (34) to cause the same rise in iodine value as feeding of the same amount of original peanut oil, iodine value 85; and inclusion of butterfat in a cow's diet was found by Hill and Palmer (37) to cause an appreciable alteration in the character of the butterfat produced.

Time Lag in, and Persistency of, Effects of Dietary Fat on Butterfat.

The effects of adding a fat to the diet on the properties of butterfat are usually shown within 12–48 hours of the time of ingestion (1, 54, 63, 80, 81), but the attainment of maximum effect may take much longer, e.g., 2–4 weeks (8, 25). Mayhead and Barnicoat (57) found that with feeding of 8 oz. of peanut oil daily to cows the effect on the iodine value reached a maximum within 3–4 days, and with feeding of 16 oz. the maximum effect was reached in 10 days. With whale-oil drenching, 300 ml. twice daily, McDowall *et al.* (54) found evidence of the maximum effect being reached in 5–6 days.

When the high-fat diet is fed for a long time, the effect on the butterfat may persist (Allen (1)), but under some conditions the cow may "outgrow" the change and the properties of the butterfat return to more normal values (11, 21, 86). In the present investigation the effects of drenching with linseed oil, soya-bean oil, and peanut oil were shown within one day of commencement of drenching, and rose steadily during the period of treatment. The three-day treatment period was not sufficiently long to provide information on the time needed for maximum change.

After cessation of feeding of a high-fat diet there is usually an early commencement of a return to normal values for butterfat properties, but the effects may persist for some time (80, 81).

Attempts to trace the effect of the dietary fat of cattle on the depot fats have not always been successful (82); but Hoflund *et al.* (38) found that unsaturated acids fed to a cow before calving were stored in the depot fat and could still be detected in the milk three weeks after calving, and Glascock *et al.* (27) found that after feeding labelled stearic acid to a cow there were active constituents in the milk fat for 37 days. In Trials I and II (drenching with whale oil (54)), and in III, IV, and VI of the present investigation, (Figs. 1, 2, and 4) there was an almost immediate commencement of return of butterfat properties to normal after discontinuance of drenching, but several days were required before the effects of the three days' drenching had entirely disappeared. This persistence of the effect of the drenched oils indicates that there had

been some deposition of the added fat in the depots followed by slow withdrawal over a period of several days after cessation of treatment.

Earlier Findings on Effects of Linseed Oil, Soya-bean Oil, Tallow and Peanut Oil on Butterfat Properties. Feeding of linseed oil is known to cause a rise in the degree of unsaturation of butterfat (9, 15, 22, 32, 36, 37, 72, 80). The extent of changes naturally varies with variation in the dose rate and variation in the period of linseed oil feeding, and also probably because of the operation of modifying factors (a) to (f) above. Hilditch (32) states that linseed oil produces no change in the proportion of lower fatty acids in butterfat and that the only significant alteration is an increase in the content of oleic acid, balanced by a reduction in the contents of palmitic/myristic and stearic acids. Some workers (32, 36, 59) found no change in Reichert value, while others (9, 37) found some reduction, and Johansson and Claesson (45) state that with intensive linseed feeding the Reichert value of the butterfat can be reduced to 16.

Feeding of *soya-bean oil* also is known to cause an increase in iodine value of the butterfat (4, 7, 8, 35, 39, 40, 64). Some workers report a simultaneous depression of the Reichert value (4, 8, 45, 61, 85).

Feeding of *tallow* to milking cows is reported to have only a minor effect on butterfat properties (30, 37, 42). In the experiments of Hill and Palmer (37) there was a depression in the saponification value with no appreciable change in iodine value or refractive index, but the saponification value of the butterfat before fat-feeding was high.

Feeding of *peanut oil* gives changes in butterfat properties similar in most respects to those described for feeding with linseed and soya-bean oil (12, 34, 39, 57, 61).

Comparison of Effects of Oils used as Drenches on Butterfat Properties. The changes in the properties of butterfat caused by drenching with 300 ml. (276 g.) twice daily for three days as found in the present investigation (see above and McDowall *et al.* (54))

TABLE 7. SUMMARY OF MAXIMUM EFFECTS OF DRENCHING WITH 300 ml. (276 g.) OF OILS TWICE DAILY FOR 3 DAYS (TRIALS, I, III, IV, V, VII)
(Data arranged in order of iodine value of fat administered)

Maximum Changes in Properties of Butterfat						
Oil Drenched	Iodine Value of Oil	Iodine Value	Refractive Index	Softening Point (°C.)	Saponification Value	Reichert Value
Linseed oil	175	+9.5	+0.0013	±0	-4	+1
Whale oil	137	+21	+0.0027	-4.4	-3	-6
Soya-bean oil	134	+10	+0.0022	+1.2	-7	-1
Peanut oil	98	+9	+0.0015	+0.4, 1.0	-9	-2.5
Tallow*	50	±0	±0	±0	-1.5	±0

* Dose rate only 125 ml. twice daily.

are summarised in Table 7. Since these drenching experiments were done over a short period, and at a time (November-December, 1954) when normally the properties of New Zealand butterfat are fairly uniform (see Cox and McDowall (13)), the results provide a comparison of what would be the effects of the different oils under comparable conditions.

Iodine value. The figures are in agreement with the generalization that fats or oils of high iodine value cause a rise in iodine value of the butterfat. They are in keeping also, however, with the conclusion of Jarl (44) that there is no close proportionality between iodine value of the feed fat and change in iodine value of the butterfat. Thus whale oil, iodine value 137, caused a change in iodine value twice as great as did linseed oil, iodine value 175; and linseed, soya-bean, and peanut oils, with respective iodine values 175, 134, and 98, caused approximately the same rise in iodine value of the butterfat.

The differences in fatty acid composition of the oils administered (see Table 8) consist mainly in differences in the distribution of the tri-, di-, and mono-unsaturation. Hilditch (32) has shown that the main effect of the ingestion of linseed oil on the fatty acids of butterfat is an increase in the oleic acid content, and that only small proportions of the linolenic acid from the linseed oil pass into the butterfat. The cow appears to have the capacity to hydrogenate the more highly unsaturated acids to form oleic acid or its isomers (see also McDowall *et al.* (54)).

It was found by Shorland *et al.* (75) that hydrogenation of the linolenic acid of grass fats could be effected in the rumen. Since in Trial VIII there was no appreciable effect on butterfat properties from the daily ingestion of 300 ml. of peanut oil along with the pasture, it seems reasonable to conclude that the intimate admixture of the oils with the herbage has permitted hydrogenation to proceed further than when the oil was administered as a drench.

Refractive index. In all the Trials the changes in refractive index of the butterfat were closely related to the changes in iodine value. This is evident from the remarkable similarity in the change of direction of the curves for iodine value and refractive index in Figs. 1-4, and is in agreement with the findings of Platon and Olsson (67) and other workers.

Softening point. Despite the comparative uniformity of the changes in iodine value (approximately 10 units) resulting from drenching with 600 ml. of linseed, soya-bean, and peanut oils daily, there were differences in the changes in softening point. Linseed oil did not cause any change in softening point, whereas soya-bean oil and peanut oil caused a rise* of approximately 1°C. The reasons for these divergences from the more usual relationship that rise in iodine value is accompanied by a fall in softening point are not evident from the data in Tables 7 and 8. Although fall in content of volatile acids, as indicated by a fall in Reichert value, is usually accompanied by a rise in softening point, the changes in Reichert value shown in Table 7 are not sufficient to provide an explanation for the changes in softening point in relation to the changes in iodine value. The irregularities may have been due to

*Compare the similar effect of feeding of cottonseed oil in causing a simultaneous rise in both iodine value and melting point of butterfat (21).

TABLE 8. COMPARISON OF AVERAGE FATTY-ACID COMPOSITION OF OILS AND FATS (AFTER HILDITCH (33))

Fatty Acid	Linseed Oil	Soya-bean Oil	Peanut Oil	Beef	Mutton
<i>Saturated</i>					
C ₁₂ (lauric)	—	—	—	—	0.2–1.3
C ₁₄ (myristic)	—	—	—	2.3	2.9–4.1
C ₁₆ (palmitic)	6–16	7–10	6–10	24–30	24–25
C ₁₈ (stearic)		2–5	3–6	21–26	15–22
C ₂₀₋₂₂		1–3	5–8	0.4–1.3	0.7
<i>Unsaturated</i>					
C ₁₄	—			0.4	0.5
C ₁₆	—			1.7–2.7	1.7–2.6
C ₁₈ (–2H) oleic	13–36	22–30	40–64	38–42	42–45
C ₁₈ (–4H) linoleic	10–25	60–50	18–38	1.7–2	2.2–5.0
C ₁₈ (–6H) linolenic	60–30	5–9	—	—	0.9–1.8
C ₂₀₋₂₂	—	—	—	0.1–0.5	—
Actual iodine value of sample used as drench	175	134	98	50	

variation in the proportion of oleic acid isomers in the final butterfat, resulting from the rumen hydrogenation reactions on the di- and tri-enoic acids (56, 75), or they may have been due to variations in the fatty acid distribution in the glycerides of the butterfat.

Saponification value. The relatively large fall in saponification value from the feeding of peanut oil may have been due to passage of some of the arachidic (C₂₀) acid from the peanut oil to the butterfat. Bowes (6) detected arachidic acid in goat butterfat 72 hours after peanut oil was consumed. In the present case, however, some of the fall in saponification value was probably a direct result of the reduction in proportion of volatile acids indicated by the fall of 2.5 units in Reichert value. Hilditch and Jasperson (34) found a distinct fall in content of C₄–C₁₀ acids in butterfat from cows given 8 oz. of peanut oil daily.

Reichert value. Of the oils used in Trials III–VI peanut oil was the only one to give any marked change in Reichert value.

Effect of Oil Drenching on Quality of Commercial Milk, Cream, and Butter

(a) *Flavour.* The flavours produced in milk by the drenching with oils would not normally be removed in the equipment used for pasteurization in the market milk plant. If drenching at the high dose rates of 300 ml. twice daily were adopted for bloat treatment or prophylaxis on any considerable scale, even for a short period, it would be expected, from the results in the present investigation, that with linseed oil and soya-bean oil some off-flavour of commercial significance would appear in the milk. If only a few cows in a herd were drenched, the dilution with milk from untreated cows could be sufficient to render the effect of these oils on flavour relatively unimportant.

Although some portion of the off-flavour in cream that would result from drenching with linseed oil and soya-bean oil would probably be removed during the deodorization process commonly applied before the cream is made into butter, it is unlikely that complete removal of this off-flavour (or of the oily flavour caused by whale oil, see Trials I and II, McDowall *et al.* (54)) would be obtained.

(b) *Physical properties of butter.* The effects of the oil drenchings on the physical properties of the butter cannot readily be diagnosed from a study of the changes in the butterfat characteristics shown in Table 7. A rise in iodine value usually leads to production of a softer butter, and feeding of fats tending to cause increase in iodine value has frequently been recommended as a means of obtaining a softer body in butter from cows fed on concentrates during the winter period (20, 21, 31, 43, 66, 80). When added to the diet of cows at a time when the butter is of normal body, however, these oils can cause an excessive softening of the body and the development of other undesirable qualities (31). The relation between iodine value of butterfat and physical properties of butter (like that between iodine value and melting point of butterfat, see above), however, is not consistent. Nevens and Tracy (64), for example, found an increasing greasiness in the butter as the proportion of soya beans in the ration of cows was increased to 2 lb. daily. Dutta *et al.* (18) found an increase in firmness of butter (accompanied by some tendency to greasiness in body) when the cows' diet was supplemented with peanut oil, although the change was accompanied by a rise in the iodine value of the butterfat; and Hill and Palmer (37) found considerable differences in hardness of butterfats with only a slight range of variation in iodine value.

There is a wide difference in the body characteristics of New Zealand spring and autumn butters, although the butterfats produced at these times may have the same iodine value (13). Some part of these differences in body may be attributed to the differences in content of lower fatty acids in the butterfat, but it seems likely that part of it at any rate is due to variation in the glyceride structure of the butterfat (34, 35, 37) or to presence of stereoisomers of the unsaturated fatty acids (32, 77). Body of butter is affected both by the character and proportion of the fat crystals and by the proportion and distribution of the residual oil (51, p. 644). In buttermaking practice these factors can be controlled to some extent by adjustment of the cream-cooling

and churning techniques, but it may not be possible to compensate fully for extensive changes in butterfat properties resulting from drenching of cows with vegetable oils at the high dose rates (17, 65, 87).

In New Zealand, the use of oils for bloat treatment and prophylaxis is likely to be required mainly during September-December. After the middle of October the butterfat has reached somewhere near its minimum iodine value (13), as was the case at the time of Trials III-VI, when drenching with 600 ml. daily of linseed, soya-bean, and peanut oil was found to cause sharp changes in iodine value. Although, owing to the operation of the disturbing factors listed earlier, prognostications of the effects of these changes on the physical properties of butter are open to error, it would be expected that there would be some softening of the butter, with a tendency to greasiness in body.

The absence of change in butterfat characteristics with feeding of 300 ml. of peanut oil sprayed on pasture (Trial VIII), on the other hand, does not necessarily signify that use of a similar peanut-oil treatment on a wide scale would not cause any change in the physical properties of the butter. The effect of administration of peanut oil in this way on butter consistency could only be established by carrying the investigation to the stage of actual buttermaking trials (as has recently been done by Dibbern and Koenen (16) in a study of the effects of some concentrate feeds). It may be assumed, however, with reasonable confidence from the results in Fig. 7 that any effects on the physical properties of the butter would not be of critical importance.

(c) *Keeping quality.* There is no evidence to indicate whether changes in iodine value of the butterfat such as occur when oils are given at high dose rates to cows at pasture will have any significant effect on the keeping quality of butter (see, however, 43, 56).

CHOICE OF OILS FOR USE IN TREATMENT AND PREVENTION OF BLOAT REVIEW AND CONCLUSION

It is clearly desirable that a material for field use as a therapeutant for bloat should not adversely affect the production or properties of milk or butterfat. The aim of the several investigations of the series on this subject (McDowall *et al.* (52, 54, and the present paper)) has been to determine to what extent the various oils available fulfil these requirements. The materials chosen for trial, viz., heavy liquid paraffin, whale oil, emulsified tallow, and the three vegetable products, linseed, soya-bean, and peanut oils, were those found by Reid and Johns (70) to offer most promise for the treatment and prevention of bloat. They were all equally effective for this purpose, and all were available commercially.

Heavy liquid paraffin at a dose rate of 75 ml. twice daily for 26 days had no significant influence on the yield or composition of milk (McDowall *et al.* (52)). Its only effect on the butterfat was a 40-50% reduction in the carotene content and a 20% reduction in the tocopherol content. The changes were a reflection of changes in the levels of these substances in the blood, and they have been shown to be proportional to the dose rate (McGillivray (55)). Further investigation is necessary before their full significance, particularly with regard to effects on animal health, can be determined.

Whale oil given at a dose rate of 300 ml. twice daily caused reductions in the milk yield, butterfat test, and butterfat yield, it led to the appearance of strong taints in the milk, cream, and butter, and it induced extensive changes in the characteristics of the butterfat (McDowall *et al.* (54)). It was therefore considered unsuitable for use in bloat treatment or prophylaxis.

Emulsified ruminant tallow had only minor effects on the properties studied, but the preparation employed was found to be unsuitable because of a number of physical difficulties in its commercial use—the emulsion was not stable during storage, it required further dilution with water to make it free-flowing, and it contained small aggregates of unemulsified fat which blocked the strainers and nozzles of spraying appliances (Reid (69)). If these defects could be overcome, emulsified tallow would appear likely to be a suitable material for field use.

The vegetable oils drenched at the high dose rate of 300 ml. twice daily had negligible effects on milk yield, but they all caused some undesirable changes in the flavour of milk, cream, and butter, or in the butterfat characteristics. At this high dose rate, peanut oil had the least effect on flavour. Drenching of this oil at the medium dose rate of 150 ml. twice daily had no effect on yield or flavour and a smaller effect on butterfat characteristics than treatment at the high dose rate. In these trials, therefore, the materials found to be most suitable for use at high dose rates in farming practice are emulsified tallow (with the reservation made above) and peanut oil. Because of the effects of peanut oil on butterfat properties, it would seem undesirable to use the high dose rate on more than a small proportion of the herd at a time.

Drenching with peanut oil at the lower dose rates (120 ml. or less daily) did not cause appreciable changes in milk yield, milk composition, or butterfat properties. Hence it is probable that at the dose rates recommended for treatment by drenching (120 ml., Reid and Johns (70)) or for control by addition to the drinking water or by spraying on pasture (90–180 ml., Reid (69)) the other vegetable oils would show a similar proportionate decrease in intensity of effect. Where the oil is administered as a spray on pasture, and so is consumed by the cows along with the feed, it seems likely that all the vegetable oils investigated would be innocuous at the recommended dose rates, and that in general farming practice any of them could safely be given in this way to the whole herd over a long period. Linseed oil has already been widely administered by pasture spraying on commercial farms, including farms supplying town milk, and so far there have not been any complaints of effect on milk or cream quality. Very crude peanut oil, offensive to the human but apparently not to the cow's palate, has been given by pasture spraying without causing tainting of the milk or cream. In Trial VIII in which peanut oil was sprayed on pasture at twice the dose rate recommended in commercial practice, (300 ml. as against 90–180 ml.) there was no observed effect on the butterfat characteristics during a three-weeks' treatment period. The indications are, therefore, that choice of the material to be used for spraying can be made on the basis of factors such as availability, cost, and physical properties.

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REFERENCES

1. ALLEN, N. N. 1934: *J. Dairy Sci.* 17: 379.
2. ALLEN, N. N.; FITCH, J. B. 1941: *J. Dairy Sci.* 24: 516.
3. ANDERSON, W. E.; WILLIAMS, H. H. 1937: *Physiol. Rev.* 17: 355.
4. BAINTEK, K.; TOTH, P.; KOVACS, L. 1955: *Agrartud. egy.* (Seen only in *Dairy Sci. Abstr.* 18: 815).
5. BALCH, C. C.; BALCH, D. A.; BARTLETT, S.; COX, C. P.; ROWLAND, S. J. 1952: *J. Dairy Res.* 19: 39.
6. BOWES, O. C. 1915: *J. Biol. Chem.* 22: 11.
7. BRATTON, R. W.; EPPLE, W. F.; WILBUR, J. W.; HILTON, J. H. 1938: *J. Dairy Sci.* 21: A109.
8. BROWN, W. C.; DUSTMAN, R. B.; WEAKLEY, C. E. 1941: *J. Dairy Sci.* 15: 265.
9. BROZZETTI, P. 1947: *Mondo Del Latte*, Dec. p. 11.
10. BUSCHMANN, A. 1930: *Tierernahrung* 1: 129 (quoted by Williams, Cannon, and Espe⁸⁰).
11. CANNON, C. Y.; ESPE, D. L.; BIRD, E. W. 1942: *Iowa agric. Exp. Sta. annu. Rep.* 1: 128.
12. CHANNON, H. J.; DRUMMOND, J. C.; GOLDING, J. 1924: *Analyst* 49: 311.
13. COX, G. A.; McDOWALL, F. H. 1948: *J. Dairy Res.* 15: 377.
14. CRANFIELD, H. T. 1916: *Analyst* 41: 336.
15. DANN, W. J.; MOORE, T.; BOOTH, R. G.; GOLDING, J.; KON, S. K. 1935: *Biochem. J.* 29: 138.
16. DIBBERN, H.; KOENEN, K. 1956: *Proc. 14th int. Dairy Congr.* 2(1): 123.
17. DOLBY, R. M. 1949: *J. Dairy Res.* 16: 336.
18. DUTTA, M. C.; FRANCISCO, J. S.; KAMAL, S.; MACKIJANI, J. K.; SOUNDERARAJAN, R. 1937: *Agric. Live-Stk India* 7: 503. (Seen only in *Chem. Abstr.* 32: 2231.)
19. DYKSTRA, N. D.; DAMMERS, J.; FRENS, A. M. 1953: *Versl. landbouwk. Onderz., 'S-Gravenhage*. 596.
20. ECKLES, C. H.; PALMER, L. S. 1916: *Miss. agric. Exp. Sta. Res. Bull.* 25.
21. ———— 1916: *Miss agric. Exp. Sta. Res. Bull.* 27.
22. ECKSTEIN, H. C. 1933: *J. Biol. Chem.* 103: 135.
23. ESPE, D.; CANNON, C. Y. 1939: *J. Dairy Sci.* 22: 799.
24. ESPE, D.; SMITH, V. R. 1952: "The Secretion of Milk". 291 pp. Iowa State College Press, Ames, Iowa.
25. FRYE, J. B.; CANNON, C. Y.; BIRD, E. W. 1950: *J. Dairy Sci.* 33: 257.
26. GARNER, F. H.; SANDERS, H. G. 1938: *J. agric. Sci.* 28: 541.
27. GLASCOCK, R. F.; DUNCOMBE, W. G.; REINIUS, L. R. 1956: *Biochem. J.* 62: 535.
28. GREENBANK, G. R. 1952: *J. Dairy Sci.* 35: 486.
29. HANSEN, R. P.; SHORLAND, F. B. 1952: *Biochem. J.* 52: 207.
30. HARLAND, F. G.; STULL, J. W.; DAVIS, R. N. 1955: *Proc. W. Div. Amer. Dairy Sci. Ass.* p. 58. (Seen only in *Dairy Sci. Abstr.* 18: 25).
31. HERZER, F. H.; MOORE, J. S.; COWSERT, W. C. 1939: *Minn. agric. Exp. Sta. Tech. Bull.* 25: 62.
32. HILDITCH, T. P. 1937: *Analyst*, 62: 250.
33. ———— 1956: "The Chemical Constitution of the Natural Fats". 664 pp. Chapman Hall, London.
34. HILDITCH, T. P.; JASPERSON, H. 1943: *Biochem. J.* 37: 238.
35. HILDITCH, T. P.; SLEIGHTHOLME, J. J. 1931: *Ibid.* 25: 507.

36. HILDITCH, T. P.; THOMPSON, H. M. 1936: *Ibid.* 30: 677.
37. HILL, O. J.; PALMER, L. S. 1938: *J. Dairy Sci.* 21: 529.
38. HOFLUND, S.; HOLMBERG, J.; SELLMANN, G. 1956: *Cornell Vet.* 45: 254.
39. HOLLAND, E. B.; BUCKLEY, J. P. 1918: *J. agric. Res.* 12: 719.
40. HOLLAND, E. B.; GARVEY, M. E.; PIERCE, H. B.; MESSER, A. C.; ARCHIBALD, J. G.; DUNBAR, C. O. 1923: *J. agric. Res.* 24: 365.
41. HORN, V.; MUHL, E. 1937: *Tierernährung* 9: 1. (Seen only in *Chem. Abstr.* 31: 3584).
42. HORTON, O. H.; KENDALL, K. A.; NEVENS, W. B.; HANSEN, R. G. 1956: *J. Dairy Sci.* 39: 1461.
43. JAEGUM, E.; HEDEMAN, H. 1953: *Maelkeritidende* 66(33): 753. (Seen only in *Dairy Sci. Abstr.* 17: 203).
44. JARL, F. 1949: *Proc. 12th int. Dairy Congr.* 1: 117.
45. JOHANSSON, I.; CLAESSON, O. 1957: "Progress in the Physiology of Farm Animals (Hammond)" Vol. 3, p. 1005.
46. JOHNS, A. T. 1954: *N.Z. J. Sci. Tech.* A36: 289.
47. LEROY, A. M. 1949: *Proc. 12th int. Dairy Congr.* 1: 21.
48. LINDSEY, J. B.; HOLLAND, E. B.; SMITH, P. H. 1908: *Miss. agric. Exp. Sta. 21st annu. Rep.* 2: 66.
49. LOOSLI, J. K.; LUCAS, H. L.; MAYNARD, L. A. 1945: *J. Dairy Sci.* 28: 147.
50. McCANDLISH, A. C.; STRUTHERS, J. P. 1935: *J. Dairy Res.* 6: 303.
51. McDOWALL, F. H. 1953: "The Buttermaker's Manual". 1577 pp. N.Z. University Press, Wellington.
52. McDOWALL, F. H.; MCGILLIVRAY, W. A.; REID, C. S. W. 1957: *N.Z. J. Sci. Tech.* A38: 839.
53. McDOWALL, F. H.; PATCHELL, M. R. (In press) *J. Dairy Res.*
54. McDOWALL, F. H.; PATCHELL, M. R.; REID, C. S. W. 1957: *N.Z. J. Sci. Tech.* A38: 1036.
55. MCGILLIVRAY, W. A. 1957: *N.Z. J. Sci. Tech.* A38: 878.
56. MATTESSON, S.; THOME, K. E.; SWARTLING, P. 1951: *Medd. Mejeriförs. Malmö* 33. (Seen only in *Dairy Sci. Abstr.* 14: 474).
57. MAYHEAD, J. W.; BARNICOAT, C. R. 1956: *J. Dairy Res.* 23: 238.
58. MAYNARD, L. A.; GARDNER, K. E.; HODSON, A. 1939: *Cornell agric. Exp. Sta. Bull.* 722.
59. MAYNARD, L. A.; LOOSLI, J. K.; McCAY, C. M. 1941: *Cornell agric. Exp. Sta. Bull.* 753.
60. MAYNARD, L. A.; McCAY, C. M. 1934: *Cornell agric. Exp. Sta. Bull.* 593.
61. MOGHUL, H. K.; SINGH, I. P.; PAUL, T. M.; ANANTAKRISHNAN, C. P. 1948: *Indian J. Dairy Sci.* 1(4): 111.
62. MONROE, C. F.; KRAUSS, W. E. 1943: *Ohio agric. Exp. Sta. Bull.* 644.
63. NEVENS, W. B.; ALLEMAN, M. B.; PECK, L. T. 1926: *J. Dairy Sci.* 9: 307.
64. NEVENS, W. B.; TRACY, P. H. 1928: *Ibid.* 11: 479.
65. PALMER, L. S.; CROCKETT, D. P. 1917: *Ibid.* 1: 235.
66. PEDERSEN, A. H. 1953: *Proc. 13th int. Dairy Congr.* II: 108.
67. PLATON, B.; OLSSON, T. 1941: *Medd. Schwed. Statens. Mejeriförsök.* 8.
68. POWELL, E. B. 1939: *J. Dairy Sci.* 22: 453.
69. REID, C. S. W. (in press): *N.Z. J. agric. Res.*
70. REID, C. S. W.; JOHNS, A. T. 1957: *N.Z. J. Sci. Tech.* A38: 908.
71. SAARINEN, P.; LONNFORS, M. 1956: *Maataloust. Aikakausk.* 28(2): 109 (Seen only in *Dairy Sci. Abstr.* 18: 1013).
72. SHEEHY, E. J. 1931: *Proc. 9th int. Dairy Congr.* 1: 76.
73. ———— 1933: *J. Dep. Agric. Ireland* 32: 18.
74. SHORLAND, F. B. 1955: "Progress in the Chemistry of Fats and Other Lipids". p. 275. (Holman-Lundberg-Malkin) Pergamon Press, London.
75. SHORLAND, F. B.; WEENINK, R. O.; JOHNS, A. T. 1955: *Nature* 175: 1129.
76. SMITH, J. A. B.; DASTUR, N. N. 1938: *Biochem. J.* 32: 1868.
77. SMITH, L. M.; FREEMAN, N. K.; JACK, E. L. 1954: *J. Dairy Sci.* 37: 399.

78. SOUTH CAROLINA EXP. STA. REP. 1929: 54 (Seen only in *Exp. Sta. Rec.* 62: 665).
79. STODDARD, G. E.; ALLEN, N. N.; PETERSON, W. H. 1939: *J. Anim. Sci.* 8: 630.
80. STORGARDS, T. 1939: *Meijerit. Aikakausk.* 1(2): 27. (Seen only in *Dairy Sci. Abstr.* 2: 263).
81. SUTTON, T. S.; BROWN, J. B.; JOHNSTON, E. W. 1932: *J. Dairy Sci.* 15: 209.
82. THOMAS, B. H.; CUTHBERTSON, C. C.; BEARD, F. 1935: *Proc. 27th Meeting Amer. Soc. Anim. Prod.*: 193.
83. TYZNIK, W.; ALLEN, N. N. 1951: *J. Dairy Sci.* 34: 493.
84. WENNERSTROEM, B. 1940: *Tierernährung.* 12: 207. (Seen only in *Chem. Abstr.* 35: 1528).
85. WILLIAMS, N. K.; CANNON, C. Y.; ESPE, D. 1939: *J. Dairy Sci.* 22: 442.
86. ———— 1943: *Ibid.* 26: 241.
87. WILSTER, G. H.; STOUT, R. E.; STEIN, R. W.; HAAG, J. D.; JONES, I. R. 1942: *Oreg. agric. Exp. Sta. Bull.* 414.
88. WOODS, C. D. 1905: *U.S. Bur. Anim. Ind. Circ.* 75.

A COMPARISON BETWEEN MEASURED AND CALCULATED SOIL MOISTURE DEFICIT

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Summary

Thornthwaite's method of calculating potential evaporation from mean daily temperature was used as a method of estimating day-by-day soil moisture changes in the top 12 inches of the Lismore stony silt loam.

The results were compared with measured changes in soil moisture obtained by gravimetric determinations on soil samples.

On non-irrigated areas, the agreement was good at moisture levels above wilting point, particularly over the early part of the season.

On the area irrigated at 1.2 in. deficit, the agreement was good (within ± 0.25 in. in twenty-three out of thirty-one irrigations).

For the 2.4 in. deficit, there was a general tendency for the deficit to be over-estimated by the calculation method.

The results indicate that, with certain limitations, the Thornthwaite method can be applied under Canterbury conditions to both non-irrigated and irrigated areas, and is simple and accurate enough for estimating times of irrigation.

INTRODUCTION

One of the problems of importance in irrigation agriculture is the accurate measurement of the amount of moisture in the soil. It is only with a knowledge of this that an efficient irrigation programme can be carried out.

There appears to be as yet no quick and accurate way of measuring moisture levels in the soil, particularly for those soils which for some reason or other, (e.g. the presence of stones) are considered difficult in this respect. As many of the light Canterbury soils fall into this category, some attention has been given to the methods available for the estimation of moisture levels from meteorological data. In particular, Thornthwaite's method of calculating potential evapotranspiration from the mean daily air temperature has been used. Results obtained by using this method of calculating deficit have been compared with measured levels of soil moisture obtained by the taking and drying of soil samples.

This has been done for areas which were not irrigated and which would therefore be dry for fairly long periods in a dry season, and also for areas which were irrigated and in which the soil moisture was kept above certain levels.

The investigation was carried out on the Lismore stony silt loam on areas sown in permanent close-grazed sheep pasture of perennial rye-grass and white clover. The soil consists of about 7 in. of light-grey-brown stony silt loam over 7 in. of brownish-yellow stony silt loam. It is shallow, flat, well-drained, and mainly alluvial and aeolian. The soil type covers an area of approximately 350 square miles and the total area covered by soils in the Lismore Series (all of which are similar, varying mainly in the quantity of stones present and the depth of soil) is about 775 square miles.

The Winchmore Irrigation Research Station is situated in the centre of the Ashburton-Lyndhurst Irrigation Scheme, about 11 miles from Ashburton. On the scheme, irrigation is carried out by the border-dyke method, which is a controlled surface-flooding of the ground. Applications of water at each irrigation range normally from 3 to 5 inches.

METHODS

The Measurement of Soil Moisture

Moisture levels in the soil were measured gravimetrically: samples were taken with a 1 in. diameter core sampler at 0-4 in. depth. Samples were weighed, dried overnight at 105°C., reweighed, and the results expressed as percentage moisture on the oven-dry weight of soil. Six samples were taken from an area to give an average soil moisture.

The average depth of soil on areas prepared for border irrigation is approximately 12 in.; because of the number of stones in the soil, it is difficult to obtain 0-12 in. samples, and regular sampling at this depth was not possible. Sampling was therefore confined to the top 4 in., and a general relationship used to convert these results to the equivalent moisture levels for the 0-12 in. depth. The general relationship between percentage moisture 0-4 in. and 0-12 in. was obtained over several seasons and is given in Table 1.

The conversion of percentage moisture (0-12 in.) to moisture deficit (0-12 in.) was obtained by using an average volume weight figure and allowing for the number of stones present. "Moisture deficit" or "deficit" is the quantity of water, expressed in inches, required to bring the 0-12 in. depth of soil from any particular moisture level back to field capacity. The equivalent moisture deficits for a range of soil moisture values are also given in Table 1.

TABLE 1.

Soil Moisture 0-4 in. (%)	Equivalent Soil Moisture 0-12 in. (%)	Equivalent Moisture Deficit 0-12 in. (in.)
30.0	26.0	0.00
25.0	22.0	0.60
20.0	18.0	1.20
15.0	14.0	1.80
10.0	10.0	2.40

For the sake of clarity, soil moisture levels are referred to as obtained, 0-4 in. depth, but the equivalent deficit figures are expressed in relation to the 0-12 in. depth.

The field capacity of the soil measured in the top four inches varies between 25% and 32%. Figures of 27.0% for non-irrigated and 30.0% for irrigated areas can be taken as average values. Field capacity of 30% for the 0-4 in. depth corresponds to 26% for the 0-12 in.

depth and is zero moisture deficit. Wilting point is approximately 10%, and past results have indicated that when the top 4 in. has reached this level, the 0–12 in. depth will also be very close to wilting point. On irrigated soil, wilting point corresponds to a deficit of 2.40 in., and on non-irrigated soil, to a deficit of 2.04 in.

Method of Calculating Deficit

The basic method used is due to Thornthwaite (1948). All calculations have been carried out using daily rates of potential evapotranspiration, as outlined by Mather (1950).

The daily values obtained were added together to give a cumulative deficit, the rainfall being subtracted. Experience had shown that the soil was always at field capacity during July and August and that the soil moisture level usually commenced to drop during September. September 1st was therefore taken as the date on which to commence the calculations, the soil being at field capacity—zero deficit—on that date. Calculations were continued until 30 April, by which time low soil temperatures and not moisture had usually become the limiting factor for growth.

In the case of non-irrigated areas, the cumulative deficit was not calculated beyond wilting point (a deficit of 2.04 in.), on account of Mather's assumption (1954) in applying the Thornthwaite approach—"water is lost from the soil at a rate determined by the potential evapotranspiration as long as the soil moisture is above wilting point".

For irrigated soil, the deficit reached just prior to each irrigation was calculated. Enough irrigation water was always applied to raise the top 12 in. of soil to field capacity and would, therefore, reduce any possible deficit to zero.

RESULTS

Non-irrigated Area

Results have been obtained for four seasons, 1952–53, 1953–54, 1954–55, and 1955–56. The first three seasons are shown in Figs. 1–3.

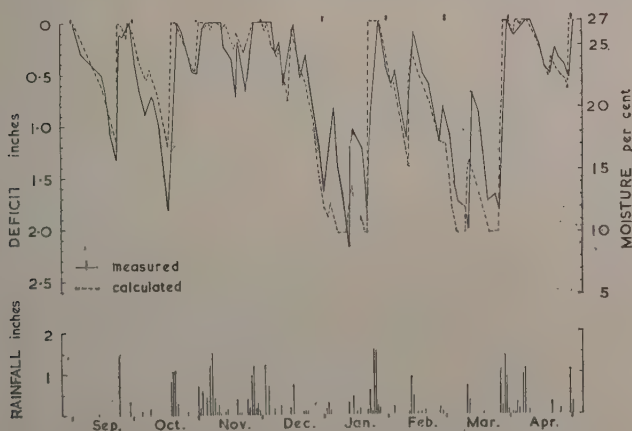


Fig. 1.—Non-irrigated. 1952–53.

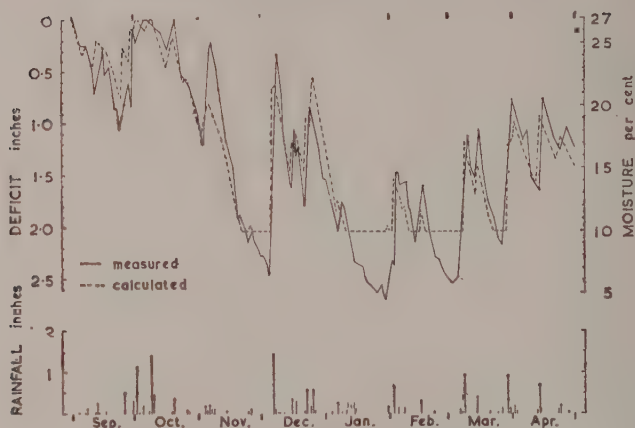


Fig. 2.—Non-irrigated. 1953-54.

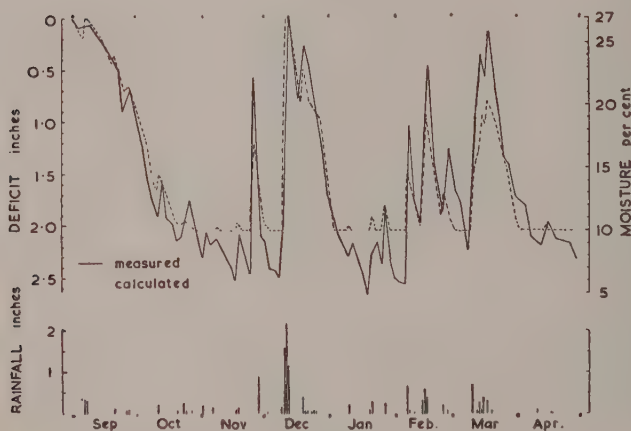


Fig. 3.—Non-irrigated. 1954-55.

Agreement between the measured and calculated deficit is good over the range from field capacity to wilting point. For the reason mentioned above, the calculation of deficit is not extended beyond wilting point, although the measured soil moisture falls below this point for considerable periods in some seasons. Consequently, comparison is not possible below wilting point. However, the periods when the deficit is calculated as being at 2.04 in. (approximately wilting point), agree very well with the periods when the soil moisture is measured as being at or below this level.

Irrigated Areas

Two irrigation treatments were chosen for this investigation. On the first of these, irrigation water was applied when the percentage moisture in the top 4 in. reached 20% (corresponding to a deficit of

TABLE 2. IRRIGATION TREATMENT AT 20% SOIL MOISTURE MEASURED AND CALCULATED DEFICITS

1953-54					
Period and Date of Irrigation	No. of Days	Moisture at Irrig. (%)	Equiv. Deficit. (in.)	Calculated Deficit (in.)	Difference (in.)
1. 1 Sept.-17 Nov.	77	18.0	1.44	1.67	+0.23
2. 18 Nov.-1 Dec.	13	17.0	1.56	1.47	-0.09
3. 2 Dec.-6 Jan.	36	18.8	1.34	1.16	-0.18
4. 7 Jan.-18 Jan.	11	19.6	1.25	1.15	-0.10
5. 19 Jan.-27 Jan.	8	20.7	1.12	1.16	+0.04
6. 28 Jan.-19 Feb.	22	20.0	1.20	1.48	+0.28
7. 20 Feb.-2 Mar.	10	20.5	1.14	1.23	+0.09
Total			9.05	9.32	
Mean		19.2	1.29	1.33	+0.04
1954-55					
1. 1 Sept.-5 Oct.	34	21.5	1.02	1.17	+0.15
2. 6 Oct.-19 Oct.	13	20.0	1.20	0.77	-0.43
3. 20 Oct.-10 Nov.	21	20.8	1.10	1.14	+0.04
4. 11 Nov.-23 Nov.	12	20.4	1.15	1.24	+0.09
5. 24 Nov.-4 Dec.	10	20.7	1.12	0.98	-0.14
6. 5 Dec.-30 Dec.	25	19.7	1.24	1.44	+0.20
7. 31 Dec.-6 Jan.	7	19.9	1.21	0.90	-0.31
8. 7 Jan.-17 Jan.	10	19.7	1.24	1.25	+0.01
9. 18 Jan.-1 Feb.	14	19.0	1.32	1.26	-0.06
10. 2 Feb.-8 Feb.	6	21.8	0.98	0.87	-0.11
11. 9 Feb.-25 Feb.	16	21.8	0.98	1.01	+0.03
12. 26 Feb.-10 Mar.	12	21.6	1.01	1.37	+0.36
13. 11 Mar.-4 Apr.	24	19.8	1.22	1.51	+0.29
Total			14.79	14.91	
Mean		20.5	1.14	1.15	+0.01
1955-56					
1. 1 Sept.-14 Oct.	43	19.6	1.25	1.08	-0.17
2. 15 Oct.-2 Nov.	18	19.6	1.25	1.13	-0.12
3. 3 Nov.-14 Nov.	11	20.8	1.10	0.84	-0.26
4. 15 Nov.-7 Dec.	22	19.3	1.28	1.17	-0.11
5. 8 Dec.-21 Dec.	13	19.8	1.22	1.60	+0.38
6. 22 Dec.-5 Jan.	15	18.9	1.33	1.34	+0.01
7. 6 Jan.-13 Jan.	7	18.0	1.44	1.08	-0.36
8. 14 Jan.-21 Jan.	7	20.2	1.18	1.39	+0.21
9. 22 Jan.-10 Feb.	20	20.8	1.10	0.87	-0.23
10. 11 Feb.-28 Feb.	17	19.1	1.31	1.47	+0.16
11. 29 Feb.-12 Mar.	13	20.5	1.14	1.30	+0.16
Total			13.60	13.27	
Mean		19.7	1.24	1.21	-0.03

1.2 in. in the 0-12 in. zone), and in the second treatment water was applied when the moisture in the top 4 in. dropped to 10%-11% (a deficit of approximately 2.4 in. in the 0-12 in. zone). In practice it was not possible to irrigate at exactly the required moisture level, and, for the three seasons studied, the average levels were 19.2%, 20.5%, and 19.7% for the first treatment, and 11.6%, 11.0%, and 11.4% for the second.

The first treatment (20%) represents almost optimum irrigation, the second (10%-11%) in which water is applied at the wilting point of the soil is probably near the minimum irrigation that should be applied.

TABLE 3. IRRIGATION TREATMENT AT 10% SOIL MOISTURE MEASURED AND CALCULATED DEFICITS

Period and Date of Irrigation	No. of Days	Moisture at Irrig. (%)	Equiv. Deficit (in.)	Calculated Deficit (in.)	Differences (in.)
1953-54					
1. 1 Sept.-23 Nov.	83	11.4	2.23	2.33	+0.10
2. 24 Nov.-18 Jan.	55	10.9	2.29	2.32	+0.03
3. 19 Jan.-20 Feb.	32	12.6	2.09	2.40	+0.31
Total			6.61	7.05	
Mean		11.6	2.20	2.35	+0.15
1954-55					
1. 1 Sept.-22 Oct.	51	10.4	2.35	2.10	-0.25
2. 23 Oct.-2 Dec.	40	11.0	2.28	2.44	+0.16
3. 3 Dec.-6 Jan.	34	11.8	2.18	2.34	+0.16
4. 7 Jan.-1 Feb.	25	11.6	2.21	2.41	+0.20
5. 2 Feb.-29 Apr.	86	10.3	2.36	2.40	+0.04
Total			11.38	11.69	
Mean		11.0	2.28	2.34	+0.06
1955-56					
1. 1 Sept.-9 Nov.	69	11.3	2.24	2.17	-0.07
2. 10 Nov.-12 Dec.	32	11.4	2.23	1.89	-0.34
3. 13 Dec.-6 Jan.	24	11.8	2.18	2.40	+0.22
4. 7 Jan.-21 Jan.	14	11.3	2.24	2.27	+0.03
5. 22 Jan.-28 Feb.	37	11.3	2.24	2.34	+0.10
Total			11.13	11.07	
Mean		11.4	2.23	2.21	-0.02

The calculated and measured deficits developed at each irrigation throughout the season were compared.

For the 20% treatment (Table 2), corresponding to a 1.2 in. deficit, in 1953-54 the agreement between the two methods was within ± 0.28 in. The periods between irrigation ranged from 77 days to 9 days. In 1954-55, for the same treatment, the agreement was within ± 0.30 in. except for three periods. These were from 6 to 19 October (when the calculated value under-estimated the deficit by 0.43 in.), 31 December to 6 January (underestimated by 0.31 in.) and 26 February to 10 March (over-estimated by 0.36 in.). During 1955-56, agreement between the two methods was good, except for two periods, 8 to 21 December (calculated deficit over-estimated by 0.38 in.) and 6 to 13 January (under-estimated by 0.36 in.). The results for this treatment for 1954-55 are shown in Fig. 4.

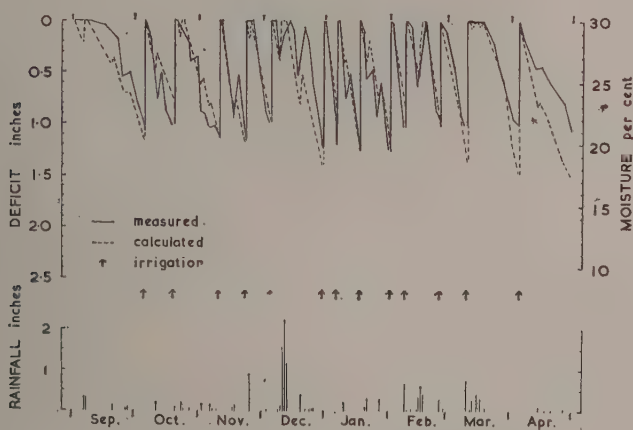


Fig. 4.—Irrigated to 20% soil moisture. 1954-55.

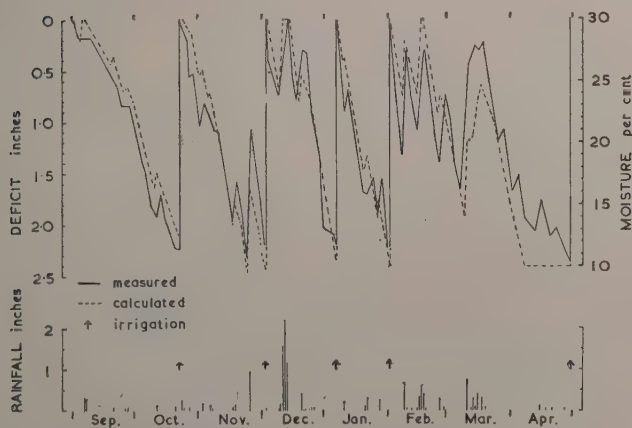


Fig. 5.—Irrigated to 10%-11% soil moisture. 1954-55.

For the 10%–11% treatment (Table 3), corresponding to a deficit of 2.4 in., the agreement is almost as good, although there is a general tendency for the deficit to be over-estimated. Results for 1953–54, 1954–55, and 1955–56 are given in Table 3, and for 1954–55 in Fig. 5. On some occasions the deficit was calculated to slightly more than 2.4 in. Although the deficit should strictly not be calculated beyond wilting point, these figures have been left as the difference is slight and well within the errors involved. One occasion, however, (period 5, 1954–55) the calculated deficit would have increased to 3.00 in. before the irrigation was applied. In this case the error introduced would have been large, and the deficit was not calculated beyond 2.4 in. This period is referred to below (Discussion).

The dates at which irrigation would be applied (that is the dates when the moisture was estimated to reach a deficit of 1.2 in.) can be calculated, and compared with the actual dates of irrigation. Close agreement could not be expected, if only for the reason that irrigations were frequently carried out just above or just below the required level. For instance, on some occasions, owing to the practical difficulties involved, water was applied when the soil moisture was above 21% and the irrigation was followed by heavy rain. In calculating the irrigations on paper, this rain would have postponed irrigation.

For the 1953–54 season, however, the agreement was fairly good for both treatments, being always within five days and frequently within one or two days.

For the 1954–55 season, on the 1.2 in. deficit treatment, the agreement was not as good. The first irrigation of the season was applied on 5 October (calculated date, 6 October), and the second on 19 October. By this time, the calculated deficit was only 0.77 in., and, consequently, the next calculated irrigation was delayed until 1 November. This had the effect of throwing out the calculated dates until December. Through December and up to early February, the agreement was within three days. Three irrigations applied on 8 February, 25 February, and 10 March were followed the day after by falls of rain of 0.67 in., 0.28 in., and 0.74 in. In two of these cases the rain was heavy enough to eliminate the necessity for an irrigation and consequently the number of irrigations on a calculated basis was less than the number actually applied.

For the 1955–56 season, eleven irrigations were applied. On a calculated basis, the number was nine, eight of which were within three days of the actual dates. The two extra irrigation dates were followed by rainfall as in 1954–55.

Despite the differences outlined above, it is very likely that if the Thornthwaite method had been used to estimate the dates of irrigation, the total pasture production would be very similar.

DISCUSSION

In general, the agreement between the two methods is good. For several reasons, a very close agreement could not be expected, and the following sources of error are apparent:

- (a) Because of sampling variation, the measured soil moisture could not be expected to give a more accurate estimate of moisture

conditions than $\pm 1.0\%$, and the volume weight figure, used to convert this percentage to inches of water per 12 in. depth is an average figure, based on relatively few determinations.

The value of field capacity is assumed to be constant throughout the season. Although this is a reasonably correct assumption on the more frequently irrigated treatment, it is by no means true on the less frequently irrigated, or 2.4 in. deficit treatment. In most cases on the latter treatment, the field capacity would be lower than 30.0%. This would have the effect of decreasing the measured deficit, and hence increasing the difference obtained between the two methods. It was considered however, that any method used in practice would have to assume the constancy of field capacity, and this has, therefore, been done.

- (b) Thornthwaite's calculation based on mean daily screen temperature, rainfall, and possible hours of sunshine, does not take into consideration the effects of wind and dew. It seems likely that both these factors would influence the rate of evapotranspiration for pasture and that, in particular, the effect of the strong Föhn winds experienced at Winchmore might be marked.

A high percentage of warm, dry, north-west winds (of the Föhn type) in the total wind miles during an irrigation period might explain such discrepancies as period 2, Table 2 (1954-55), where the calculated deficit was considerably lower than the measured.

Heavy dew is another factor that would tend to influence the rate of evapotranspiration, particularly during the autumn months, (March, April). The presence of surface moisture on the pasture for a considerable part of the day may effectively decrease the demand for moisture on the soil. The actual rate of evapotranspiration may therefore be less than the calculated, e.g. period 5, Table 3 (1954-55). Although there was a total rainfall for April 1955 of only 0.18 in., the soil moisture showed little signs of dropping. The 2.4 in. deficit treatment was at 16% soil moisture at the beginning of the month, and had only dropped to 10.2% by the 29th. By the Thornthwaite method, an irrigation would have been required on 7 April, but was not actually needed until the 29th.

CONCLUSIONS

Thornthwaite's method of calculating potential evapotranspiration can be applied to the estimation of soil moisture levels above wilting point, in the surface foot of soil, and to the estimation of irrigation requirements on the light Canterbury soils. By calculating the day-to-day values of evapotranspiration and from these the daily changes in soil moisture deficit, a reliable picture can be obtained of the moisture conditions of the soil throughout a season. The application of the method to planned irrigation is twofold. It could be used to estimate times of irrigation during a dry season, and on a wider scale can form the basis of an investigation into the irrigation requirements of an area. It can therefore be used to supply information on irrigation requirements of past seasons, and a complete study of all seasons in Mid-Canterbury since 1912-13 is in progress.

It should be emphasised that the results outlined above apply only to the particular soil and other conditions described. Until further work

has been carried out, it would be unwise to conclude that the Thornthwaite method can be applied to other soil and climatic conditions in New Zealand. It would also be inadvisable at this stage to discuss the theoretical significance—if any—of the agreement found.

ACKNOWLEDGEMENT

Thanks are due to members of the staff of the Rukuhia Soil Research Station for helpful comments and criticisms.

REFERENCES

- MATHER, JOHN, R. 1950: "Manual of Evapotranspiration." *Supplement to Int. Rep. 10, Johns Hopkins Univ. Lab. Climatol.*
- 1954: The Determination of Soil Moisture From Climatic Data. *Bull. Amer. met. Soc.* 35: 63-8.
- THORNTHWAIT, C. W. 1948: An Approach Toward a Rational Classification of Climate. *Geogr. Rev.* 38: 55-94.
- THORNTHWAIT, C. W.; MATHER, J. R. 1955: The Water Balance. *Drexel Inst. Technol. Publ. Climatol.* 8(1).

SOME DECAY TABLES FOR USE WITH RADIOACTIVE TRACERS

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In radioactive tracer work it is desirable to have some readily available source of decay factors. This often takes the form of a graph, but other methods are in use, for instance, Knauss (1948) has devised a slide rule method for calculating decay and Kirby and Kramer (1955) have published tables for the naturally occurring radioactive isotopes.

Similar tables, for twelve commonly used, artificially produced isotopes, have proved useful in this laboratory and are presented below. These tables show the fraction of initial activity remaining after a given time, up to ten half-lives, and are set out in two sections, the first of which gives factors for the first $3\frac{1}{3}$ half-lives. In this section the time interval is approximately 0.01 half-lives, but in the second section a larger interval of about 0.05 half-lives is used. An exception to this general plan will be found in the table for ^{60}Co , which is given to one half-life only. For easy reference the tables are set out in the familiar form used for tables of logarithms.

Collections of values for half-lives have been made by the United States Bureau of Standards (1950), the A.E.R.E. Harwell (1950), and by Hollander, Perlman, and Seaborg (1953). After comparing these sources I chose the "best values" of Hollander *et al.* as likely to be the most accurate ones available. The half-lives used in preparing Tables 2a to 2m are set out in Table 1.

ACKNOWLEDGEMENT

I am grateful to Mr. I. W. Bayne, Mr. K. R. Millar, and Mr. B. J. Roddick for assistance with the calculations.

TABLE 1. RADIOACTIVE HALF-LIVES

Isotope	Half-life	Reference
$^{24}_{11}\text{Na}$	15.06 hours	Sreb (1951a)
$^{32}_{15}\text{P}$	14.30 days	Cacciapuoti (1938); Bayly (1950)
$^{35}_{16}\text{S}$	87.1 days	Hendricks <i>et al.</i> (1943)
$^{42}_{19}\text{K}$	12.44 hours	Siegbahn (1947)
$^{45}_{20}\text{Ca}$	152 days	Matthews and Pool (1947)
$^{51}_{24}\text{Cr}$	27.75 days	Lyon (1952)
$^{59}_{26}\text{Fe}$	45.1 days	Schuman and Camilli (1951)
$^{60}_{27}\text{Co}$	5.27 years	Tobailem (1951)
$^{64}_{29}\text{Cu}$	12.80 hours	Rabinowicz (1950)
$^{65}_{30}\text{Zn}$	250 days	Livingood and Seaborg (1939)
$^{131}_{53}\text{I}$	8.141 days	Sreb (1951b)
$^{198}_{79}\text{Au}$	2.69 days	Saxon and Heller (1949); Silver (1951)

TABLE 2a

RADIOACTIVE DECAY OF ^{24}Na

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Hours	Minutes					Subtract Mean Differences Minutes				
	0	10	20	30	40	50	2	4	6	8
	x 10 ⁻⁴									
0	10000	9924	9848	9773	9698	9624	15	30	45	60
1	9950	9877	9805	9733	9662	9591	14	29	43	57
2	9921	9851	9782	9713	9645	9577	14	27	41	55
3	8710	8644	8578	8512	8447	8383	13	26	39	52
4	8949	8255	8192	8129	8067	8005	13	25	38	50
5	7944	7683	7623	7563	7504	7445	12	24	36	48
6	7587	7529	7471	7414	7358	7302	11	23	34	46
7	7244	7190	7135	7081	7027	6973	11	22	33	44
8	6920	6867	6814	6762	6710	6659	10	21	31	42
9	6608	6558	6508	6458	6409	6360	10	20	30	40
10	6311	6263	6215	6168	6121	6074	9	19	28	38
11	6027	5981	5935	5890	5845	5800	9	18	27	36
12	5756	5712	5668	5625	5582	5539	9	17	26	35
13	5497	5455	5413	5372	5331	5290	8	16	25	33
14	5250	5210	5170	5130	5091	5052	8	15	24	31
15	5014	4976	4938	4900	4862	4825	8	16	23	30
16	4788	4751	4715	4679	4643	4608	7	14	22	29
17	4573	4538	4503	4469	4435	4401	7	14	21	27
18	4477	4434	4391	4348	4305	4263	7	13	20	26
19	4474	4439	4407	4376	4345	4313	6	13	19	25
20	4083	3953	3923	3893	3863	3833	6	12	18	24
21	3804	3775	3746	3717	3689	3661	6	11	17	23
22	3633	3605	3578	3551	3524	3496	5	11	16	22
23	3469	3443	3417	3391	3365	3339	5	10	16	21
24	3415	3388	3363	3338	3313	3288	5	10	15	20
25	3466	3440	3416	3392	3368	3345	5	9	14	19
26	3222	2999	2976	2953	2930	2908	5	9	14	18
27	2846	2864	2842	2820	2799	2777	4	9	13	17
28	2716	2735	2714	2694	2673	2652	4	8	12	17
29	2632	2612	2592	2572	2553	2534	4	8	12	16
30	2514	2495	2476	2457	2438	2419	4	8	11	15
31	2501	2482	2464	2446	2428	2411	4	7	11	14
32	2293	2275	2258	2241	2224	2206	3	7	10	14
33	2189	2173	2156	2140	2124	2107	3	6	10	13
34	2091	2075	2059	2044	2026	2012	3	6	9	13
35	1997	1982	1967	1952	1937	1922	3	6	9	12
36	1907	1893	1878	1864	1850	1835	3	6	9	11
37	1823	1808	1794	1780	1766	1753	3	6	8	11
38	1739	1726	1713	1700	1687	1674	3	5	8	10
39	1662	1649	1636	1623	1611	1599	3	5	8	10
40	1587	1574	1562	1550	1539	1527	2	5	7	9
41	1516	1504	1492	1481	1469	1458	2	5	7	9
42	1457	1436	1425	1414	1403	1393	2	4	6	9
43	1387	1371	1356	1341	1326	1310	2	4	6	8
44	1320	1310	1300	1290	1280	1270	2	4	6	8
45	1260	1251	1241	1232	1222	1213	2	4	6	7
46	1204	1195	1185	1176	1167	1158	2	4	5	7
47	1150	1141	1132	1123	1115	1106	2	4	5	7
48	1097	1089	1081	1072	1064	1056	2	3	5	6
49	1048	1040	1033	1025	1017	1009	2	3	5	6
50	1001						1	3	4	6

Hours	Hours										Subtract Mean Differences Minutes				
	0	1	2	3	4	5	6	7	8	9	10	20	30	40	50
					$\times 10^{-5}$										
50		9562	9133	8722	8329	7955	7597	7255	6928	6616	67	134	201	268	335
60	6319	6035	5764	5505	5257	5020	4794	4579	4373	4176	55	109	164	218	273
70	3988	3809	3638	3474	3317	3168	3026	2890	2760	2636	43	86	129	173	217
80	2517	2404	2296	2193	2094	2000	1910	1824	1742	1664	27	55	82	109	137
90	1589	1517	1449	1384	1322	1262	1205	1151	1099	1050	22	43	65	87	109
100	1003										17	37	50	62	86
					$\times 10^{-6}$						11	27	41	55	69
100		9575	9144	8733	8340	7965	7607	7265	6938	6626	69	128	206	276	344
110	6328	6043	5771	5512	5264	5027	4801	4585	4379	4182	55	109	164	218	273
120	3994	3814	3642	3478	3322	3173	3030	2894	2764	2640	43	87	130	173	217
130	2521	2407	2298	2194	2096	2002	1912	1826	1744	1666	34	69	103	136	172
140	1591	1519	1451	1386	1324	1264	1207	1152	1101	1037	27	55	82	110	142
150	1004										22	43	65	87	109
											17	35	52	69	87
											11	27	41	55	69
											9	17	26	35	43
											8	15	23	30	38

TABLE 2c.

RADIOACTIVE DECAY OF ^{35}S

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Days	Days					Subtract Mean Differences		
	0	1	2	3	4	Hours		
	5	6	7	8	9	6	12	18
	$\times 10^{-4}$							
0	10000	9921	9842	9764	9686	20	39	59
	9609	9533	9458	9383	9309	19	37	56
10	9235	9162	9089	9017	8946	18	36	54
	8875	8804	8734	8665	8597	17	35	52
20	8529	8461	8394	8327	8261	17	33	50
	8196	8131	8066	8002	7939	16	32	48
30	7876	7814	7752	7690	7629	15	31	46
	7569	7509	7449	7390	7332	15	30	44
40	7274	7216	7159	7102	7046	14	28	43
	6990	6935	6880	6825	6771	14	27	41
50	6717	6664	6611	6559	6507	13	26	39
	6455	6404	6353	6303	6253	13	25	38
60	6203	6154	6105	6057	6009	12	24	36
	5961	5914	5867	5821	5775	12	23	35
70	5729	5683	5630	5593	5549	11	22	34
	5505	5461	5418	5375	5333	11	21	32
80	5291	5249	5207	5166	5125	10	21	31
	5084	5044	5004	4964	4925	10	20	30
90	4886	4847	4809	4771	4733	10	19	29
	4696	4658	4621	4584	4548	9	18	28
100	4512	4476	4441	4405	4371	9	18	26
	4336	4302	4268	4234	4200	8	17	25
110	4167	4134	4101	4069	4037	8	16	24
	4005	3973	3941	3910	3879	8	16	23
120	3848	3817	3787	3757	3727	8	15	23
	3698	3669	3640	3611	3582	7	14	22
130	3554	3526	3498	3470	3442	7	14	21
	3415	3388	3361	3334	3308	7	13	20
140	3282	3256	3230	3204	3179	6	13	19
	3154	3129	3104	3080	3055	6	12	19
150	3031	3007	2983	2959	2936	6	12	18
	2913	2890	2867	2844	2821	6	11	17
160	2799	2777	2755	2733	2711	5	11	16
	2690	2669	2648	2627	2606	5	11	16
170	2585	2564	2544	2524	2504	5	10	15
	2484	2464	2445	2426	2407	5	10	14
180	2388	2369	2350	2331	2312	5	9	14
	2294	2276	2258	2240	2222	4	9	13
190	2205	2187	2170	2153	2136	4	9	13
	2119	2102	2085	2068	2052	4	8	12
200	2036	2020	2004	1988	1972	4	8	12
	1956	1940	1925	1910	1895	4	8	11
210	1880	1865	1850	1835	1821	4	7	11
	1807	1793	1779	1765	1751	4	7	11
220	1737	1723	1709	1695	1682	3	7	10
	1669	1656	1643	1630	1617	3	7	10
230	1604	1591	1578	1565	1553	3	6	9
	1541	1529	1517	1505	1493	3	6	9
240	1481	1469	1457	1445	1434	3	6	9
	1423	1412	1401	1390	1379	3	6	8
250	1368	1357	1346	1335	1324	3	5	8
	1314	1304	1294	1284	1274	3	5	8
260	1264	1254	1244	1234	1224	3	5	8
	1214	1204	1194	1185	1176	2	5	7
270	1166	1157	1148	1139	1130	2	5	7
	1121	1112	1103	1094	1085	2	4	7
280	1077	1068	1060	1052	1044	2	4	6
	1036	1027	1018	1010	1003	2	4	6

TABLE 2c (continued)

RADIOACTIVE DECAY OF ^{35}S

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

	Days										Subtract Mean Differences				
Days	0	5	10	15	20	25	30	35	40	45	Days				
	$\times 10^{-5}$										1	2	3	4	
250									9948	9560	78	156	234	312	
300	9187	8828	8484	8153	7835	7529	7236	6954	6682	6421	66	133	189	265	
350	6171	5930	5699	5477	5263	5058	4860	4671	4489	4314	54	109	163	217	
400	4145	3984	3828	3678	3535	3397	3265	3138	3015	2898	45	89	134	178	
450	2785	2676	2572	2471	2375	2282	2193	2108	2025	1946	37	73	110	146	
500	1870	1797	1727	1660	1595	1533	1473	1416	1362	1310	30	60	90	120	
550	1258	1207	1160	1115	1072	1030					24	49	74	98	
											20	40	60	80	
											16	33	49	66	
											13	27	41	54	
											11	22	33	44	
											9	18	27	35	
	$\times 10^{-6}$														
550							9896	9510	9139	8782	73	146	218	291	
600	8440	8111	7794	7490	7198	6917	6647	6388	6139	5899	61	122	183	244	
650	5669	5448	5236	5031	4835	4646	4465	4291	4124	3963	50	100	150	200	
700	3808	3660	3517	3380	3248	3121	2999	2882	2770	2662	41	82	123	164	
750	2558	2458	2362	2270	2182	2097	2015	1936	1861	1788	34	67	101	134	
800	1718	1651	1587	1525	1465	1408	1353	1301	1250	1201	27	55	82	109	
850	1154	1109	1066	1024							23	45	68	90	
											18	37	55	74	
											15	30	45	61	
											12	25	37	50	
											10	20	30	41	
											9	17	26	34	

TABLE 24

RADIOACTIVE DECAY OF ^{42}K

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Hours	Minutes					Subtract Mean Differences	
	0	6	12	18	24	Minutes	
	30	36	42	48	54	2	4
	$\times 10^{-4}$						
0	10000	9944	9889	9834	9780	18	37
	9726	9671	9617	9564	9511	18	36
1	9458	9406	9353	9301	9250	17	35
	9198	9147	9096	9046	8995	17	34
2	8945	8896	8846	8797	8748	16	33
	8700	8651	8603	8555	8508	16	32
3	8461	8414	8367	8320	8274	15	31
	8228	8182	8137	8092	8047	15	30
4	8002	7958	7913	7870	7827	15	29
	7782	7739	7696	7653	7611	14	29
5	7568	7526	7485	7443	7402	14	28
	7360	7320	7279	7238	7198	13	27
6	7158	7119	7079	7040	7001	13	26
	6963	6924	6885	6846	6808	13	26
7	6770	6733	6695	6658	6621	12	25
	6584	6548	6511	6475	6439	12	24
8	6403	6368	6332	6297	6262	12	23
	6227	6193	6159	6124	6090	11	23
9	6056	6023	5989	5956	5923	11	22
	5890	5857	5825	5792	5760	11	22
10	5728	5696	5665	5633	5602	11	21
	5571	5540	5509	5478	5448	10	20
11	5418	5388	5358	5328	5298	10	20
	5269	5240	5211	5182	5153	10	19
12	5124	5096	5067	5039	5011	9	19
	4983	4956	4928	4901	4873	9	18
13	4846	4819	4793	4766	4740	9	18
	4713	4687	4661	4635	4610	9	17
14	4584	4558	4533	4508	4483	8	17
	4458	4433	4408	4384	4360	8	16
15	4335	4311	4287	4263	4240	8	16
	4216	4193	4170	4146	4123	8	15
16	4100	4078	4055	4032	4010	7	15
	3988	3966	3944	3922	3900	7	14
17	3878	3857	3836	3814	3793	7	14
	3772	3751	3730	3709	3688	7	14
18	3668	3648	3627	3607	3587	7	14
	3567	3547	3528	3508	3489	7	13
19	3469	3450	3431	3412	3393	6	13
	3374	3355	3336	3318	3300	6	12
20	3281	3263	3245	3227	3209	6	12
	3191	3173	3156	3138	3121	6	12
21	3103	3086	3069	3052	3035	6	11
	3018	3001	2985	2968	2951	5	11
22	2935	2919	2903	2887	2871	5	11
	2855	2839	2823	2807	2792	5	11
23	2776	2761	2745	2730	2715	5	10
	2700	2685	2670	2655	2640	5	10
24	2626	2611	2597	2582	2568	5	10
	2553	2539	2525	2511	2497	5	9
25	2483	2469	2456	2442	2429	5	9
	2415	2402	2388	2375	2362	4	9
26	2349	2336	2323	2310	2297	4	9
	2284	2272	2259	2246	2234	4	8
27	2221	2209	2197	2185	2173	4	8
	2161	2149	2137	2125	2113	4	8
28	2101	2089	2078	2066	2055	4	8
	2043	2032	2021	2009	1998	4	7
29	1987	1976	1965	1954	1943	4	7
	1933	1922	1911	1901	1890	4	7
30	1880	1869	1859	1848	1838	3	7
	1828	1818	1808	1798	1788	3	7
31	1778	1768	1758	1748	1738	3	6
	1729	1719	1710	1700	1691	3	6
32	1681	1672	1663	1653	1644	3	6
	1635	1626	1617	1608	1599	3	6
33	1590	1581	1573	1564	1555	3	6
	1547	1538	1529	1521	1512	3	6
34	1504	1496	1487	1479	1471	3	5
	1462	1454	1446	1438	1430	3	5
35	1422	1415	1407	1399	1391	3	5
	1383	1376	1368	1360	1353	3	5
36	1345	1338	1330	1323	1316	2	5
	1308	1301	1294	1287	1280	2	5
37	1272	1265	1258	1251	1244	2	5
	1237	1231	1224	1217	1210	2	4
38	1204	1197	1190	1184	1177	2	4
	1170	1164	1157	1151	1145	2	4
39	1138	1132	1126	1120	1113	2	4
	1107	1101	1095	1089	1083	2	4
40	1077	1071	1065	1059	1053	2	4
	1047	1041	1035	1029	1024	2	4
41	1018	1013	1007	1001		2	4

TABLE 2a (continued)

RADIOACTIVE DECAY OF ⁴²K
FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Hours	Hours										Subtract Mean Differences Minutes		
	0	1	2	3	4	5	6	7	8	9	15	30	45
	x 10 ⁻⁵												
40			9631	9109	8615	8148	7707	7289	6894	6520	124	247	371
50	6167	5833	5517	5218	4935	4668	4415	4176	3949	3735	99	198	297
60	3533	3341	3160	2989	2827	2674	2529	2392	2262	2140	75	149	225
70	2024	1914	1810	1712	1619	1531	1448	1370	1296	1226	57	114	170
80	1159	1096	1037								43	86	129
	x 10 ⁻⁶										33	65	98
80			9807	9275		8773	8297	7848	7422	7020	25	49	74
90	6640	6280	5939	5617	5314	5026	4753	4496	4252	4021	19	37	56
100	3803	3597	3402	3218	3044	2879	2722	2574	2435	2303	15	30	44
110	2179	2061	1949	1843	1743	1649	1560	1475	1395	1319			
120	1249	1180	1116	1056	1000								

TABLE 2e.
RADIOACTIVE DECAY OF ^{45}Ca
FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Days	Days										Subtract Mean Differences Hours		
	0	1	2	3	4	5	6	7	8	9	6	12	18
	$\times 10^{-4}$												
0	10000	9955	9909	9864	9819	9774	9730	9686	9642	9598	11	22	33
10	9524	9511	9468	9424	9381	9339	9296	9254	9212	9170	11	21	32
20	9128	9087	9045	9004	8963	8923	8882	8842	8810	8761	10	20	31
30	8721	8682	8642	8603	8564	8525	8486	8447	8409	8371	10	19	29
40	8333	8295	8257	8219	8182	8145	8108	8071	8034	7998	9	19	28
50	7961	7925	7889	7853	7817	7782	7746	7711	7676	7641	9	18	27
60	7606	7572	7537	7503	7469	7435	7401	7367	7334	7301	8	16	25
70	7277	7234	7201	7169	7136	7103	7071	7039	7007	6975	8	16	24
80	6943	6912	6880	6849	6818	6787	6756	6725	6695	6664	8	15	23
90	6634	6604	6574	6544	6514	6484	6455	6425	6396	6367	7	15	22
100	6338	6309	6280	6252	6223	6195	6167	6139	6111	6083	7	14	21
110	6056	6028	6001	5973	5946	5919	5892	5865	5839	5812	7	13	20
120	5786	5759	5733	5707	5681	5655	5629	5604	5578	5553	6	13	19
130	5528	5503	5478	5453	5428	5403	5378	5354	5330	5306	6	12	18
140	5281	5257	5233	5210	5186	5162	5139	5116	5092	5069	6	12	18
150	5046	5023	5000	4977	4955	4932	4910	4887	4865	4843	6	11	17
160	4821	4799	4777	4755	4733	4712	4691	4669	4648	4627	5	11	16
170	4606	4585	4564	4544	4523	4502	4481	4461	4441	4420	5	10	15
180	4400	4381	4361	4341	4321	4301	4282	4262	4243	4224	5	10	15
190	4205	4185	4166	4147	4129	4110	4091	4072	4053	4035	5	9	14
200	4017	3999	3981	3963	3945	3927	3909	3891	3873	3855	5	9	14
210	3837	3820	3803	3786	3769	3751	3734	3717	3701	3684	4	9	13
220	3667	3650	3634	3617	3601	3585	3569	3552	3536	3519	4	8	12
230	3503	3487	3471	3456	3440	3425	3409	3393	3378	3363	4	8	12
240	3347	3332	3317	3302	3287	3272	3257	3242	3227	3213	4	7	11
250	3198	3184	3169	3155	3140	3126	3112	3098	3084	3070	4	7	11
260	3056	3042	3028	3014	3000	2986	2973	2960	2946	2933	3	7	10
270	2919	2906	2893	2880	2867	2854	2841	2828	2815	2802	3	7	10
280	2789	2776	2764	2752	2739	2726	2713	2701	2689	2677	3	6	9
290	2665	2653	2641	2629	2617	2605	2593	2581	2569	2558	3	6	9
300	2546	2534	2523	2512	2500	2489	2477	2466	2455	2444	3	6	9
310	2433	2422	2411	2400	2389	2378	2367	2356	2346	2335	3	6	8
320	2324	2314	2303	2293	2282	2272	2261	2251	2241	2231	3	5	8
330	2221	2210	2200	2190	2180	2170	2161	2151	2141	2131	2	5	7
340	2122	2112	2102	2093	2083	2074	2064	2055	2046	2036	2	5	7
350	2027	2018	2009	1999	1990	1981	1972	1963	1954	1945	2	5	7
360	1937	1928	1919	1910	1902	1893	1884	1876	1867	1859	2	4	7
370	1850	1842	1833	1825	1817	1809	1800	1792	1784	1776	2	4	6
380	1768	1760	1752	1744	1736	1728	1720	1712	1704	1697	2	4	6
390	1689	1681	1674	1666	1658	1651	1643	1636	1629	1621	2	4	6
400	1614	1606	1599	1592	1585	1577	1570	1563	1556	1549	2	4	5
410	1542	1535	1528	1521	1514	1507	1500	1493	1486	1480	2	4	5
420	1473	1466	1460	1453	1446	1440	1433	1427	1420	1414	2	4	5
430	1407	1401	1395	1388	1382	1376	1369	1363	1357	1351	2	3	5
440	1345	1339	1332	1326	1320	1314	1308	1302	1296	1291	2	3	5
450	1285	1279	1273	1267	1261	1256	1250	1244	1239	1233	1	3	5
460	1227	1222	1216	1211	1205	1200	1194	1189	1183	1178	1	3	4
470	1173	1167	1162	1157	1152	1146	1141	1136	1132	1126	1	3	4
480	1120	1115	1110	1105	1100	1095	1090	1085	1080	1075	1	3	4
490	1070	1066	1061	1056	1051	1046	1042	1037	1032	1027	1	2	4
500	1023	1018	1014	1009	1004						1	2	4

Days	Days					Subtract Mean Differences Days			
	0	10	20	30	40	2	4	6	8
	50	60	70	80	90				
	$\times 10^{-5}$								
500		9772	9336	8920	8522	82	163	244	326
	8442	7780	7433	7101	6784	66	133	199	266
600	6482	6193	5917	5654	5402	52	105	157	210
	5161	4931	4711	4501	4300	42	84	126	168
700	4173	3926	3696	3483	3284	34	67	101	134
	3271	3125	2986	2853	2726	27	53	80	107
800	2604	2488	2377	2271	2170	21	42	64	85
	2073	1981	1893	1808	1727	17	34	51	68
900	1650	1577	1507	1439	1375	13	27	40	54
	1314	1255	1199	1146	1095	11	21	32	43
1000	1046								
	$\times 10^{-6}$								
1000		9994	9549	9123	8716	85	171	256	341
	8328	7957	7602	7263	6939	68	136	204	272
1100	6630	6334	6052	5782	5524	54	108	162	216
	5278	5043	4818	4603	4398	43	86	129	172
1200	4202	4015	3836	3665	3501	34	69	103	137
	3345	3196	3064	2918	2788	27	55	82	109
1300	2666	2545	2431	2322	2218	22	44	65	87
	2120	2026	1936	1850	1767	17	35	52	69
1400	1688	1613	1541	1472	1406	14	28	41	55
	1344	1284	1227	1172	1120	11	22	33	44
1500	1070	1022				9	19	28	37

TABLE 2f.

RADIOACTIVE DECAY OF ^{51}Cr

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Days	Hours								Subtract Mean Differences Hours				
	0	6	12	18	24	30	36	42	1	2	3	4	5
	$\times 10^{-4}$												
0	10000	9938	9876	9814	9753	9693	9632	9572	10	20	30	40	51
2	9513	9453	9394	9336	9278	9220	9163	9106	10	19	29	39	48
4	9049	8993	8937	8881	8826	8771	8716	8662	9	18	28	37	46
6	8608	8555	8502	8448	8396	8344	8292	8240	9	17	26	35	44
8	8189	8138	8087	8037	7987	7937	7888	7839	8	17	25	33	42
10	7790	7741	7693	7645	7598	7550	7503	7457	8	16	24	32	40
12	7410	7364	7318	7273	7227	7182	7138	7093	7	15	23	30	38
14	7049	7005	6962	6918	6875	6832	6790	6748	7	14	21	28	36
16	6706	6664	6622	6581	6540	6499	6459	6419	7	14	20	27	34
18	6379	6339	6300	6260	6221	6183	6144	6106	6	13	19	26	32
20	6068	6030	5993	5955	5918	5881	5844	5808	6	12	18	25	31
22	5772	5736	5701	5665	5630	5595	5560	5525	6	12	18	23	29
24	5491	5457	5423	5389	5356	5322	5289	5256	6	11	17	22	28
26	5224	5191	5159	5127	5095	5063	5031	5000	5	11	16	21	27
28	4969	4938	4907	4877	4846	4816	4786	4756	5	10	15	20	25
30	4727	4697	4668	4639	4610	4581	4553	4525	5	10	14	19	24
32	4497	4469	4441	4413	4386	4358	4331	4304	5	9	14	18	23
34	4277	4251	4224	4198	4172	4146	4120	4094	4	9	13	17	22
36	4069	4044	4018	3993	3969	3944	3919	3895	4	8	12	16	21
38	3874	3847	3823	3799	3775	3752	3728	3705	4	8	12	16	20
40	3682	3659	3636	3614	3591	3569	3547	3525	4	7	11	15	19
42	3503	3481	3459	3438	3416	3395	3374	3353	4	7	11	14	18
44	3332	3311	3291	3270	3250	3229	3209	3189	3	7	10	14	17
46	3170	3150	3130	3111	3091	3072	3053	3034	3	6	10	13	16
48	3015	2996	2978	2959	2941	2922	2904	2886	3	6	9	12	15
50	2868	2850	2833	2815	2798	2780	2763	2746	3	6	9	12	15
52	2728	2711	2695	2678	2661	2644	2628	2612	3	6	8	11	14
54	2596	2579	2563	2547	2531	2516	2500	2484	3	5	8	11	13
56	2469	2454	2438	2423	2408	2393	2378	2363	3	5	8	10	13
58	2349	2334	2320	2305	2291	2277	2263	2249	2	5	7	10	12
60	2235	2220	2206	2193	2179	2166	2152	2139	2	5	7	9	11
62	2125	2112	2099	2086	2073	2060	2047	2034	2	4	6	9	11
64	2022	2009	1997	1984	1972	1960	1947	1935	2	4	6	8	10
66	1923	1911	1899	1888	1876	1864	1853	1841	2	4	6	8	10
68	1830	1818	1807	1796	1784	1773	1762	1751	2	4	6	8	9
70	1740	1730	1719	1708	1697	1687	1676	1666	2	4	5	7	9
72	1656	1645	1635	1625	1615	1605	1595	1585	2	3	5	7	8
74	1575	1565	1555	1546	1536	1527	1517	1508	2	3	5	6	8
76	1498	1489	1480	1471	1462	1452	1443	1434	2	3	5	6	8
78	1425	1416	1407	1399	1390	1381	1373	1364	1	3	4	6	7
80	1356	1347	1339	1331	1322	1314	1306	1298	1	3	4	6	7
82	1290	1282	1274	1266	1258	1250	1242	1234	1	3	4	5	7
84	1227	1219	1212	1204	1197	1189	1182	1174	1	3	4	5	6
86	1167	1160	1153	1145	1138	1131	1124	1117	1	2	4	5	6
88	1110	1103	1096	1090	1083	1076	1069	1063	1	2	3	5	6
90	1056	1049	1043	1036	1030	1023	1017	1011	1	2	3	4	5
92	1005												

Days	Days					Subtract Mean Differences Days		
	0	2	4	6	8	0.5	1.0	1.5
	$\times 10^{-5}$							
90			9557	9091	8648	111	222	332
100	8227	7826	7444	7081	6737	91	182	273
110	6408	6096	5799	5516	5248	71	142	212
120	4992	4749	4517	4297	4088	55	110	166
130	3868	3699	3519	3347	3180	43	86	129
140	3029	2881	2741	2607	2480	33	67	100
150	2360	2245	2135	2031	1932	26	52	78
160	1838	1748	1663	1582	1505	20	41	61
170	1432	1362	1296	1223	1173	16	32	48
180	1115	1061	1009			13	26	39
	$\times 10^{-6}$							
180				9601	9133	114	228	342
190	8688	8264	7862	7479	7114	96	192	288
200	6768	6438	6124	5826	5542	75	150	224
210	5272	5015	4770	4537	4316	58	117	175
220	4106	3906	3716	3535	3363	45	91	136
230	3199	3043	2895	2754	2620	35	71	106
240	2492	2370	2255	2145	2040	28	55	83
250	1941	1846	1757	1672	1590	21	43	64
260	1512	1438	1368	1302	1239	17	33	50
270	1178	1120	1065	1014		13	27	40

TABLE 2g

RADIOACTIVE DECAY OF ^{59}Fe

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Days	Days					Subtract Mean Differences Hours		
	0.0 2.5	0.5 3.0	1.0 3.5	1.5 4.0	2.0 4.5	3	6	9
	$\times 10^{-4}$							
0	10000	9923	9847	9772	9697	19	38	57
	9623	9550	9477	9404	9332	18	36	54
5	9260	9189	9119	9049	8980	17	35	52
	8911	8843	8775	8708	8641	17	34	50
10	8575	8510	8445	8380	8316	16	32	48
	8252	8189	8126	8064	8002	16	31	47
15	7941	7880	7820	7760	7701	15	30	45
	7642	7583	7525	7468	7410	14	29	43
20	7354	7298	7242	7186	7131	14	28	41
	7077	7022	6968	6915	6862	13	27	40
25	6810	6758	6706	6655	6604	13	26	39
	6553	6503	6453	6403	6354	12	25	37
30	6306	6258	6210	6162	6115	12	24	36
	6068	6022	5976	5930	5885	11	23	34
35	5840	5795	5751	5707	5663	11	22	33
	5620	5577	5534	5492	5450	11	21	32
40	5408	5366	5325	5285	5244	10	20	31
	5204	5164	5125	5085	5046	10	20	29
45	5008	4969	4931	4893	4856	9	19	28
	4819	4782	4745	4709	4673	9	18	27
50	4637	4602	4567	4532	4497	9	17	26
	4463	4428	4394	4361	4327	8	17	25
55	4294	4262	4229	4196	4164	8	16	24
	4132	4101	4069	4038	4007	8	16	23
60	3977	3946	3916	3886	3856	8	15	22
	3827	3798	3768	3740	3711	7	14	22
65	3683	3654	3626	3599	3571	7	14	21
	3544	3517	3490	3463	3436	7	13	20
70	3410	3384	3358	3332	3307	6	13	19
	3282	3257	3232	3207	3182	6	12	19
75	3158	3134	3110	3086	3062	6	12	18
	3039	3016	2993	2970	2947	6	12	17
80	2924	2902	2880	2858	2836	6	11	17
	2814	2793	2771	2750	2729	5	11	16
85	2708	2687	2667	2646	2626	5	10	15
	2606	2586	2566	2547	2527	5	10	15
90	2508	2489	2470	2451	2432	5	10	14
	2413	2395	2376	2358	2340	5	9	14
95	2322	2304	2287	2269	2252	4	9	13
	2235	2218	2201	2184	2167	4	9	13
100	2150	2134	2118	2101	2085	4	8	12
	2069	2054	2038	2022	2007	4	8	12
105	1991	1976	1961	1946	1931	4	8	11
	1916	1902	1887	1873	1858	4	7	11
110	1844	1830	1816	1802	1788	4	7	10
	1775	1761	1748	1734	1721	3	7	10
115	1708	1695	1682	1669	1656	3	7	10
	1643	1631	1618	1606	1594	3	6	9
120	1581	1569	1557	1545	1534	3	6	9
	1522	1510	1499	1487	1476	3	6	9
125	1464	1453	1442	1431	1420	3	6	8
	1409	1398	1388	1377	1367	3	5	8
130	1356	1345	1335	1325	1315	3	5	8
	1305	1295	1285	1275	1266	2	5	7
135	1256	1246	1237	1227	1218	2	5	7
	1208	1199	1190	1181	1172	2	5	7
140	1163	1154	1145	1137	1128	2	4	7
	1119	1111	1102	1094	1085	2	4	6
145	1077	1069	1060	1052	1044	2	4	6
	1036	1028	1020	1013	1005	2	4	6

TABLE 2g (continued)

RADIOACTIVE DECAY OF ^{59}Fe

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Days	Days					Subtract Mean Differences Days		
	0	2	4	6	8	0.5	1.0	1.5
	$\times 10^{-5}$							
150	9972	9671	9378	9094	8819	71	142	213
160	8552	8293	8042	7798	7562	61	122	183
170	7333	7111	6896	6687	6485	52	104	157
180	6289	6099	5914	5735	5561	45	89	134
190	5393	5230	5072	4918	4769	39	77	115
200	4624	4484	4249	4217	4090	33	66	99
210	3966	3846	3729	3616	3507	28	57	85
220	3401	3298	3198	3101	3007	24	49	73
230	2916	2828	2742	2659	2579	21	42	62
240	2501	2425	2352	2281	2212	18	36	53
250	2145	2080	2017	1956	1897	15	31	46
260	1839	1783	1729	1677	1626	13	26	39
270	1577	1529	1483	1438	1395	11	23	34
280	1352	1311	1272	1233	1196	10	19	29
290	1160	1125	1091	1058	1026	8	17	25
	$\times 10^{-6}$							
300	9945	9644	9352	9069	8794	71	142	213
310	8528	8270	8020	7777	7541	61	122	182
320	7313	7092	6877	6669	6467	52	104	156
330	6271	6081	5897	5719	5546	45	89	134
340	5378	5215	5057	4904	4756	38	77	115
350	4612	4472	4337	4206	4079	33	66	98
360	3955	3835	3719	3606	3497	28	56	85
370	3391	3289	3189	3092	2999	24	48	72
380	2908	2820	2735	2652	2572	21	41	62
390	2494	2418	2345	2274	2205	18	35	53
400	2139	2074	2011	1950	1891	15	31	46
410	1834	1778	1724	1672	1622	13	26	39
420	1573	1525	1479	1434	1391	11	22	34
430	1349	1308	1268	1230	1193	10	20	29
440	1157	1122	1088	1055	1023	8	17	25

TABLE 2h
 RADIOACTIVE DECAY OF ^{60}Co
 FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Weeks	Weeks					Subtract Mean Differences					
	0	2	4	6	8	Days					
	$\times 10^{-4}$										
0	10000	9949	9899	9849	9800	7	14	21	28	35	42
10	9750	9701	9652	9603	9555						
20	9507	9459	9411	9364	9316	7	14	20	27	34	40
30	9269	9223	9176	9130	9084						
40	9038	8992	8947	8902	8857	6	13	19	25	32	38
50	8812	8768	8723	8679	8636						
60	8592	8549	8506	8463	8420	6	12	18	24	30	36
70	8377	8335	8293	8251	8210						
80	8168	8127	8086	8045	8004	6	12	17	23	29	35
90	7964	7924	7884	7844	7805						
100	7765	7726	7687	7648	7610	5	11	16	22	27	33
110	7571	7533	7495	7457	7420						
120	7382	7345	7308	7271	7234	5	11	16	21	26	31
130	7198	7162	7125	7089	7054						
140	7018	6983	6947	6912	6877	5	10	15	20	25	30
150	6843	6808	6774	6740	6706						
160	6672	6638	6605	6571	6538	5	9	14	19	24	28
170	6505	6472	6440	6407	6375						
180	6343	6311	6279	6247	6216	4	9	13	18	23	27
190	6184	6153	6122	6091	6060						
200	6030	5999	5969	5939	5909	4	9	13	18	22	26
210	5879	5850	5820	5791	5761						
220	5732	5704	5675	5646	5618	4	8	12	16	20	24
230	5589	5561	5533	5505	5477						
240	5450	5422	5395	5368	5341	4	8	11	15	19	23
250	5314	5287	5260	5234	5208						
260	5181	5155	5129	5103	5077	4	7	11	15	18	22
270	5051	5026	5001	4975	4950						
280	4925	4900	4876	4851	4827	3	7	10	14	17	21
290	4803	4778	4754	4730	4706						
300	4682	4659	4635	4612	4589	3	7	10	13	17	20
310	4565	4542	4519	4497	4474						
320	4451	4429	4407	4384	4362	3	6	9	13	16	19
330	4340	4318	4296	4275	4253						
340	4232	4210	4189	4168	4147	3	6	9	12	15	18
350	4126	4105	4085	4064	4043						
360	4023	4003	3982	3962	3942	3	6	9	11	15	17
370	3922	3903	3883	3863	3844						
380	3825	3805	3786	3767	3748	3	5	8	11	14	16
390	3729	3710	3692	3673	3654						
400	3636	3618	3599	3581	3563	3	5	8	10	13	15
410	3545	3527	3509	3492	3474						
420	3457	3439	3422	3404	3387	2	5	7	10	12	15
430	3370	3353	3336	3319	3303						
440	3286	3269	3253	3237	3220	2	5	7	9	11	14
450	3204	3188	3172	3156	3140						
460	3124	3108	3092	3077	3061	2	4	7	9	11	13
470	3046	3031	3015	3000	2985						
480	2970	2955	2940	2925	2910	2	4	6	8	11	13
490	2896	2881	2867	2852	2838						
500	2823	2809	2795	2781	2767	2	4	6	8	10	12
510	2753	2739	2725	2711	2698						
520	2684	2671	2657	2644	2630	2	4	6	8	9	11
530	2617	2604	2591	2578	2565						
540	2552	2539	2526	2513	2501	2	4	5	7	9	11

TABLE 24

RADIOACTIVE DECAY OF ^{64}Cu

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Hours	Minutes					Subtract Mean Differences	
	0	6	12	18	24	Minutes	
	30	36	42	48	54	2	4
	$\times 10^{-4}$						
0	10000	9946	9892	9839	9786	18	36
	9733	9680	9628	9576	9524	17	35
1	9473	9422	9371	9320	9270	17	34
	9220	9170	9121	9071	9022	16	33
2	8973	8925	8877	8829	8781	16	32
	8734	8687	8640	8593	8547	16	31
3	8501	8455	8409	8364	8319	15	30
	8274	8229	8184	8140	8096	15	29
4	8053	8009	7966	7923	7880	14	29
	7837	7795	7753	7711	7669	14	28
5	7628	7587	7546	7505	7465	14	27
	7424	7384	7344	7305	7265	13	26
6	7226	7187	7148	7110	7071	13	26
	7033	6995	6957	6920	6882	13	25
7	6845	6808	6771	6735	6698	12	24
	6662	6626	6590	6555	6519	12	24
8	6484	6449	6414	6380	6345	12	23
	6311	6277	6243	6209	6176	11	23
9	6142	6109	6076	6043	6011	11	22
	5978	5946	5914	5882	5850	11	21
10	5819	5788	5757	5725	5694	10	21
	5665	5633	5602	5572	5542	10	20
11	5512	5482	5453	5423	5394	10	20
	5365	5336	5307	5278	5250	10	19
12	5222	5193	5165	5137	5110	9	19
	5082	5055	5027	5000	4973	9	18
13	4946	4919	4893	4867	4840	9	18
	4814	4788	4762	4736	4711	9	17
14	4685	4660	4635	4610	4585	8	17
	4560	4535	4511	4487	4463	8	16
15	4439	4415	4391	4367	4343	8	16
	4320	4297	4273	4250	4227	8	15
16	4205	4182	4159	4137	4114	8	15
	4092	4070	4048	4026	4005	7	15
17	3983	3961	3940	3919	3898	7	14
	3877	3856	3835	3814	3793	7	14
18	3773	3753	3732	3712	3692	7	13
	3672	3652	3633	3613	3593	7	13
19	3574	3555	3536	3517	3498	6	13
	3479	3460	3441	3423	3404	6	12
20	3386	3367	3349	3331	3313	6	12
	3295	3277	3260	3242	3225	6	12
21	3207	3190	3173	3156	3139	6	11
	3122	3105	3088	3071	3055	6	11
22	3038	3022	3005	2989	2973	5	11
	2957	2941	2925	2909	2894	5	11
23	2878	2862	2847	2832	2816	5	10
	2804	2786	2771	2756	2741	5	10
24	2726	2712	2697	2682	2668	5	10
	2653	2639	2625	2611	2597	5	9
25	2583	2569	2555	2541	2527	5	9
	2514	2500	2487	2473	2460	5	9
26	2446	2433	2420	2407	2394	4	9
	2381	2368	2355	2343	2330	4	8
27	2318	2305	2293	2280	2268	4	8
	2256	2243	2231	2219	2207	4	8
28	2195	2184	2172	2160	2148	4	8
	2137	2125	2114	2102	2091	4	8
29	2080	2068	2057	2046	2035	4	7
	2024	2013	2002	1991	1981	4	7
30	1970	1959	1949	1938	1928	4	7
	1917	1907	1897	1886	1876	4	7
31	1866	1856	1846	1836	1826	3	7
	1816	1807	1797	1787	1777	3	6
32	1768	1758	1749	1739	1730	3	6
	1724	1714	1702	1693	1684	3	6
33	1675	1666	1657	1648	1639	3	6
	1630	1621	1612	1604	1595	3	6
34	1586	1578	1569	1561	1552	3	6
	1544	1536	1527	1519	1511	3	5
35	1503	1495	1487	1479	1471	3	5
	1463	1455	1447	1439	1432	3	5
36	1424	1416	1408	1401	1393	3	5
	1385	1377	1370	1363	1356	2	5
37	1348	1341	1334	1327	1320	2	5
	1312	1305	1298	1291	1284	2	5
38	1277	1270	1264	1257	1250	2	5
	1243	1237	1230	1223	1217	2	4
39	1210	1204	1197	1191	1184	2	4
	1178	1171	1165	1159	1153	2	4
40	1146	1140	1134	1128	1122	2	4
	1116	1110	1104	1098	1092	2	4
41	1086	1080	1074	1068	1063	2	4
	1057	1051	1045	1040	1034	2	4
42	1029	1023	1018	1012	1007	2	4

TABLE 21 (continued)

RADIOACTIVE DECAY OF ^{64}Cu

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Hours	Hours					Subtract Mean Differences		
	0	1	2	3	4	Minutes		
	5	6	7	8	9	15	30	45
	$\times 10^{-5}$							
40	8744	8283	7846	7433	7044	129	258	386
	6670	6318	5985	5670	5371	104	207	311
50	5088	4820	4566	4325	4097	79	158	237
	3881	3676	3482	3299	3125	60	121	181
60	2960	2804	2657	2517	2384	46	92	138
	2258	2139	2026	1920	1819	36	71	107
70	1723	1632	1546	1464	1387	27	54	80
	1314	1245	1179	1117	1058	20	41	61
80	1002					16	31	47
	$\times 10^{-6}$							
		9493	8994	8520	8071	119	237	356
90	7646	7243	6861	6499	6156	91	181	272
	5832	5525	5233	4957	4696	69	138	207
100	4449	4214	3992	3781	3582	53	106	158
	3393	3214	3045	2885	2733	40	81	121
110	2588	2452	2323	2200	2084	31	61	92
	1974	1870	1772	1678	1590	23	47	70
120	1506	1427	1352	1281	1213	18	36	54
	1149	1088	1031			15	31	46

TABLE 21
 RADIOACTIVE DECAY OF ^{65}Zn
 FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Days	Days					Subtract Mean Differences Days		
	0	2	4	6	8	0.5	1.0	1.5
	$\times 10^{-4}$							
0	10000	9945	9890	9835	9781	14	27	41
10	9727	9673	9619	9566	9513	13	27	40
20	9461	9408	9356	9304	9253	13	26	39
30	9202	9151	9100	9050	9000	13	25	38
40	8950	8901	8852	8803	8754	12	25	37
50	8705	8657	8610	8562	8515	12	24	36
60	8467	8421	8374	8328	8282	12	23	35
70	8236	8190	8145	8100	8055	11	23	34
80	8011	7967	7923	7879	7835	11	22	33
90	7792	7749	7706	7663	7621	11	21	32
100	7579	7537	7495	7454	7412	10	21	31
110	7371	7331	7290	7250	7210	10	20	30
120	7170	7130	7091	7052	7013	10	20	29
130	6974	6935	6897	6859	6821	10	19	29
140	6783	6746	6708	6671	6634	9	19	28
150	6598	6561	6525	6489	6453	9	18	27
160	6417	6382	6346	6311	6276	9	18	26
170	6242	6207	6173	6139	6105	9	17	26
180	6071	6037	6004	5971	5938	8	17	25
190	5905	5872	5840	5808	5776	8	16	24
200	5744	5712	5680	5649	5618	8	16	24
210	5587	5556	5525	5494	5464	8	15	23
220	5434	5404	5374	5344	5315	7	15	23
230	5285	5256	5227	5198	5169	7	14	22
240	5141	5112	5084	5056	5028	7	14	21
250	5000	4972	4945	4918	4890	7	14	21
260	4863	4836	4810	4783	4757	7	13	20
270	4730	4704	4678	4652	4627	6	13	19
280	4601	4576	4551	4525	4500	6	13	19
290	4475	4450	4426	4401	4377	6	12	18
300	4353	4329	4305	4281	4257	6	12	18
310	4234	4210	4187	4164	4141	6	12	17
320	4118	4095	4073	4050	4028	6	11	17
330	4005	3983	3961	3939	3918	5	11	16
340	3896	3874	3853	3832	3810	5	11	16
350	3789	3768	3747	3727	3706	5	10	15
360	3686	3665	3645	3625	3605	5	10	15
370	3585	3565	3545	3525	3506	5	10	14
380	3487	3467	3448	3429	3410	5	10	14
390	3392	3373	3354	3336	3317	5	9	14
400	3299	3281	3262	3244	3226	5	9	14
410	3209	3191	3173	3156	3138	4	9	13
420	3121	3104	3086	3069	3052	4	9	13
430	3036	3019	3002	2985	2969	4	8	12
440	2951	2935	2920	2904	2888	4	8	12
450	2872	2856	2840	2824	2809	4	8	12
460	2793	2778	2762	2747	2732	4	8	11
470	2717	2702	2687	2672	2657	4	7	11
480	2643	2628	2614	2599	2585	4	7	11
490	2570	2556	2542	2528	2514	4	7	11
500	2500	2486	2472	2459	2445	3	7	10
510	2432	2418	2405	2392	2378	3	7	10
520	2365	2352	2339	2326	2313	3	7	10
530	2300	2288	2275	2263	2250	3	6	9
540	2238	2225	2213	2201	2189	3	6	9
550	2176	2164	2152	2140	2120	3	6	9
560	2117	2106	2094	2082	2070	3	6	9
570	2059	2048	2036	2025	2014	3	6	8
580	2003	1992	1981	1970	1959	3	6	8
590	1948	1937	1926	1916	1905	3	5	8
600	1895	1884	1874	1863	1853	3	5	8
610	1843	1833	1823	1812	1802	3	5	8
620	1792	1783	1773	1763	1753	2	5	7
630	1743	1734	1724	1715	1705	2	5	7
640	1696	1686	1677	1668	1659	2	5	7
650	1650	1640	1631	1622	1613	2	5	7
660	1604	1595	1587	1578	1569	2	4	7
670	1560	1552	1543	1535	1526	2	4	6
680	1518	1509	1501	1493	1484	2	4	6
690	1476	1468	1460	1452	1444	2	4	6
700	1436	1428	1420	1412	1404	2	4	6
710	1397	1389	1381	1374	1366	2	4	6
720	1359	1351	1343	1336	1329	2	4	6
730	1321	1314	1307	1299	1292	2	4	5
740	1285	1278	1271	1264	1257	2	4	5
750	1250	1243	1236	1229	1223	2	3	5
760	1216	1209	1202	1196	1189	2	3	5
770	1183	1176	1170	1163	1157	2	3	5
780	1150	1144	1138	1132	1125	2	3	5
790	1119	1113	1106	1100	1094	2	3	5
800	1088	1082	1076	1070	1064	2	3	5
810	1058	1053	1047	1041	1035	1	3	4
820	1029	1024	1018	1013	1007	1	3	4
830	1001							

TABLE 2k (continued)

RADIOACTIVE DECAY OF ^{65}Zn

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Days	Days										Subtract Mean Differences Days			
	0	10	20	30	40	50	60	70	80	90	2	4	6	8
	$\times 10^{-5}$													
800					9740	9473	9214	8962	8717	8479	54	107	161	215
900	8247	8022	7802	7589	7381	7180	6983	6792	6607	6426	49	98	147	196
1000	6250	6079	5913	5751	5594	5441	5292	5148	5007	4870	43	85	128	171
1100	4737	4607	4481	4359	4239	4124	4011	3901	3794	3691	37	74	112	159
1200	3590	3492	3396	3303	3213	3125	3040	2957	2876	2798	32	65	97	129
1300	2721	2646	2574	2503	2435	2368	2304	2241	2179	2120	28	56	84	113
1400	2062	2005	1951	1897	1845	1795	1746	1698	1652	1606	25	50	74	98
1500	1563	1520	1478	1438	1399	1360	1323	1287	1252	1217	21	43	64	85
1600	1184	1152	1120	1090	1060	1031	1003				19	37	56	74
	$\times 10^{-6}$										16	32	48	65
1600								9753	9486	9227	14	28	42	56
1700	8975	8729	8490	8258	8032	7813	7599	7391	7189	6993	12	24	37	49
1800	6801	6615	6435	6259	6087	5921	5759	5602	5448	5299	11	22	32	43
1900	5155	5014	4876	4743	4613	4487	4365	4245	4129	4016	9	19	28	37
2000	3906	3800	3696	3595	3496	3401	3308	3218	3129	3044	8	16	24	32
2100	2960	2880	2801	2724	2650	2577	2507	2439	2372	2307	7	14	21	28
2200	2244	2182	2123	2065	2008	1953	1900	1848	1797	1748	6	12	19	24
2300	1700	1654	1609	1565	1522	1480	1440	1400	1362	1325	6	11	17	22
2400	1289	1253	1219	1186	1153	1122	1091	1061	1032	1004				

TABLE 21.
RADIOACTIVE DECAY OF ^{131}I
FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Days	Hours						Subtract Mean Differences Minutes		
	0	2	4	6	8	10	30	60	90
	12	14	16	18	20	22			
	$\times 10^{-4}$								
0	10000	9929	9859	9789	9720	9651	17	35	52
1	9583	9515	9448	9381	9315	9249	17	33	50
	9184	9119	9054	8990	8927	8864	16	32	48
2	8801	8739	8677	8616	8555	8494	15	30	46
	8434	8375	8316	8257	8198	8140	15	29	44
3	8063	8026	7969	7912	7856	7801	14	28	42
	7746	7691	7637	7583	7529	7476	13	27	40
4	7423	7374	7319	7267	7215	7164	13	26	39
	7114	7064	7013	6965	6914	6865	13	25	38
5	6817	6769	6721	6674	6627	6580	12	24	35
	6533	6487	6441	6395	6350	6305	11	23	34
6	6261	6217	6173	6129	6086	6043	11	22	33
	6000	5957	5915	5873	5832	5791	10	21	31
7	5750	5709	5669	5629	5589	5549	10	20	30
	5510	5471	5432	5394	5356	5318	10	19	29
8	5280	5243	5206	5169	5132	5096	9	18	27
	5060	5024	4989	4954	4919	4884	9	17	26
9	4850	4815	4781	4747	4713	4680	8	17	25
	4647	4615	4582	4549	4517	4485	8	16	24
10	4454	4422	4391	4360	4329	4298	8	16	23
	4268	4238	4208	4178	4148	4119	8	15	22
11	4090	4061	4033	4004	3976	3948	7	14	21
	3920	3892	3864	3837	3810	3783	7	14	20
12	3756	3729	3703	3677	3651	3625	7	13	20
	3599	3574	3549	3524	3499	3474	6	13	19
13	3449	3425	3401	3377	3353	3329	6	12	18
	3306	3283	3259	3236	3213	3191	6	12	17
14	3168	3146	3124	3102	3080	3058	6	11	17
	3036	3015	2994	2973	2951	2930	5	10	16
15	2909	2889	2869	2848	2828	2808	5	10	15
	2788	2769	2749	2730	2710	2691	5	10	14
16	2672	2653	2634	2616	2597	2579	5	9	14
	2561	2543	2525	2507	2489	2472	4	9	13
17	2454	2437	2419	2402	2385	2369	4	9	13
	2352	2335	2319	2302	2286	2270	4	8	12
18	2254	2238	2222	2206	2191	2175	4	8	12
	2160	2145	2129	2114	2099	2085	4	8	11
19	2070	2056	2041	2026	2012	1998	4	7	11
	1984	1970	1956	1942	1928	1914	3	7	10
20	1901	1887	1874	1861	1848	1835	3	7	10
	1822	1809	1796	1784	1771	1758	3	6	9
21	1746	1734	1721	1709	1697	1685	3	6	9
	1673	1661	1649	1638	1626	1615	3	6	9
22	1603	1592	1581	1569	1558	1547	3	5	8
	1536	1526	1515	1504	1493	1483	3	5	8
23	1472	1462	1452	1441	1431	1421	3	5	8
	1411	1401	1391	1381	1372	1362	3	5	7
24	1352	1343	1333	1324	1314	1305	2	5	7
	1296	1287	1278	1269	1260	1251	2	4	7
25	1242	1233	1224	1216	1207	1199	2	4	6
	1190	1182	1173	1165	1157	1149	2	4	6
26	1141	1133	1125	1117	1109	1101	2	4	6
	1093	1086	1078	1070	1063	1055	2	4	6
27	1047	1040	1033	1025	1018	1011	2	4	5
	1004						2	4	5

Days	Days.										Subtract Mean Differences Hours.				
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	2	4	6	8	12
	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5					
	$\times 10^{-5}$														
20	7775	7451	7140	6843	6557	9619	9218	8834	8466	8113	61	123	184	246	307
30						6284	6022	5771	5531	5300	50	99	149	199	249
	5079	4868	4666	4471	4284	4105	3934	3770	3614	3463	40	80	120	161	201
40	3318	3180	3048	2921	2799	2682	2570	2464	2361	2262	32	65	97	130	162
	2168	2078	1991	1908	1828	1752	1679	1609	1542	1478	26	54	79	105	131
50	1416	1357	1301	1247	1195	1145	1097	1051	1008		21	42	64	85	106
											17	34	52	69	86
60											14	28	42	56	69
											11	22	34	45	56
70											9	18	27	36	45
											7	15	22	29	37
	$\times 10^{-6}$														
50	9253	8867	8498	8144	7804					9655	67	132	201	268	335
60						7479	7167	6868	6582	6308	59	118	177	228	296
	6045	5793	5552	5320	5098	4886	4682	4487	4300	4121	48	96	143	191	239
70	3949	3785	3627	3476	3331	3192	3059	2932	2810	2692	39	77	116	154	193
	2580	2473	2370	2271	2176	2085	1998	1915	1835	1759	31	62	94	125	156
80	1686	1616	1549	1485	1423	1363	1306	1251	1199	1149	25	50	76	101	126
	1101	1055	1011								20	41	61	82	102
											17	33	50	66	83
											13	27	40	53	67
											11	22	32	43	54
											9	18	26	35	44
											7	15	22	29	37

TABLE 2a.

RADIOACTIVE DECAY OF 198 Au

FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Days	Hours	Hours					Subtract Mean Differences Minutes			
		0	0.5	1.0	1.5	2.0	2.5	6	12	18-24
x 10 ⁻⁴										
0	0	10000	9946	9893	9840	9787	9735	11	21	32 42
	3	9683	9631	9580	9528	9477	9427	10	20	31 41
	6	9376	9326	9276	9226	9177	9128	10	20	30 40
	9	9079	9030	8982	8934	8886	8839	10	19	29 38
	12	8791	8744	8697	8651	8604	8558	9	19	28 37
	15	8513	8467	8422	8376	8331	8287	9	18	27 36
	18	8243	8199	8155	8111	8068	8024	9	17	26 35
	21	7981	7939	7896	7854	7812	7770	8	17	25 34
	0	7728	7687	7646	7605	7564	7524	8	17	24 33
	3	7484	7444	7404	7364	7325	7285	8	16	24 32
1	6	7246	7208	7169	7131	7092	7054	8	15	23 31
	9	7017	6979	6942	6905	6868	6831	7	15	22 30
	12	6794	6758	6722	6686	6650	6614	7	14	21 29
	15	6579	6544	6509	6474	6439	6405	7	14	20 28
	18	6370	6336	6302	6269	6235	6202	7	13	20 27
	21	6169	6136	6103	6070	6037	6005	7	13	20 26
	0	5973	5941	5909	5878	5846	5815	6	13	19 25
	3	5784	5753	5722	5691	5661	5630	6	12	18 25
	6	5600	5570	5541	5511	5481	5452	6	12	18 24
	9	5423	5394	5365	5336	5308	5279	6	11	17 23
2	12	5251	5223	5195	5167	5139	5112	6	11	17 22
	15	5085	5057	5030	5003	4976	4950	5	11	16 22
	18	4923	4897	4871	4845	4819	4793	5	10	16 21
	0	4767	4742	4716	4691	4666	4641	5	10	15 20
	3	4616	4591	4567	4542	4518	4494	5	10	15 20
	6	4470	4446	4422	4398	4375	4352	5	9	14 19
	9	4328	4305	4282	4259	4236	4214	5	9	14 18
	12	4191	4169	4146	4124	4102	4080	4	9	13 18
	15	4058	4036	4015	3993	3972	3951	4	8	13 17
	18	3930	3909	3888	3867	3846	3825	4	8	13 17
3	0	3805	3785	3764	3744	3724	3704	4	8	12 16
	3	3684	3665	3645	3626	3606	3587	4	8	12 15
	6	3568	3549	3530	3511	3492	3473	4	8	11 15
	9	3455	3436	3418	3399	3381	3363	4	7	11 15
	12	3345	3327	3309	3292	3274	3256	4	7	11 14
	15	3239	3222	3204	3187	3170	3153	3	7	10 14
	18	3136	3120	3103	3086	3070	3053	3	7	10 13
	21	3037	3021	3005	2989	2973	2957	3	6	10 13
	0	2941	2925	2909	2894	2878	2863	3	6	9 13
	3	2847	2832	2817	2802	2787	2772	3	6	9 12
4	6	2757	2742	2728	2713	2699	2684	3	6	9 11
	9	2670	2656	2641	2627	2613	2599	3	6	8 11
	12	2585	2571	2558	2544	2530	2517	3	5	8 11
	15	2503	2490	2477	2463	2450	2437	3	5	8 11
	18	2424	2411	2398	2385	2372	2360	3	5	8 10
	21	2347	2335	2322	2310	2297	2285	2	5	7 10
	0	2273	2261	2248	2236	2224	2212	2	5	7 10
	3	2201	2189	2177	2166	2154	2142	2	5	7 9
	6	2131	2119	2108	2097	2086	2074	2	5	7 9
	9	2063	2052	2041	2030	2020	2009	2	4	7 9
5	12	1998	1987	1977	1966	1956	1945	2	4	6 8
	15	1935	1924	1914	1904	1894	1883	2	4	6 8
	18	1873	1863	1853	1843	1834	1824	2	4	6 8
	0	1814	1804	1795	1785	1775	1766	2	4	6 8
	3	1756	1747	1736	1728	1719	1710	2	4	5 7
	6	1701	1692	1683	1674	1665	1656	2	4	5 7
	9	1647	1648	1629	1621	1612	1603	2	3	5 7
	12	1595	1586	1578	1569	1561	1552	2	3	5 7
	15	1544	1536	1528	1519	1511	1503	2	3	5 7
	18	1495	1487	1479	1471	1463	1456	2	3	5 6
6	0	1448	1440	1432	1425	1417	1409	2	3	5 6
	3	1402	1394	1387	1380	1372	1365	2	3	5 6
	6	1357	1350	1343	1336	1329	1322	1	3	5 6
	9	1314	1307	1300	1293	1287	1280	1	3	4 5
	12	1273	1266	1259	1252	1246	1239	1	3	4 5
	15	1232	1226	1219	1213	1206	1200	1	3	4 5
	18	1193	1187	1181	1174	1168	1162	1	2	4 5
	0	1156	1149	1143	1137	1131	1125	1	2	4 5
	3	1119	1113	1107	1101	1095	1089	1	2	4 5
	6	1083	1078	1072	1066	1060	1055	1	2	3 5
7	9	1049	1043	1038	1032	1027	1021	1	2	3 4
	12	1016	1010	1005	1000			1	2	3 4

TABLE 2m (continued)

RADIOACTIVE DECAY OF ^{198}Au
FRACTION OF INITIAL ACTIVITY REMAINING AFTER A GIVEN TIME

Days	Hours								Subtract Mean Differences Hours	
	0	3	6	9	12	15	18	21	1	2
	$\times 10^{-5}$									
9	9837	9525	9223	8931	8647	8373	8108	7851	93	187
10	7602	7361	7128	6902	6683	6471	6266	6068	72	144
11	5875	5689	5509	5334	5164	5001	4843	4689	56	111
12	4541	4397	4257	4122	3992	3865	3743	3624	43	86
13	3509	3398	3290	3186	3085	2987	2893	2801	33	66
14	2712	2626	2543	2462	2384	2309	2236	2165	26	51
15	2096	2030	1965	1903	1843	1785	1728	1673	20	40
16	1620	1569	1519	1471	1424	1379	1335	1293	15	31
17	1252	1212	1174	1137	1101	1066	1032		12	25
	$\times 10^{-6}$									
18	9675	9369	9072	8786	8507	8236	7976	9992	105	241
19	7478	7241	7011	6789	6574	6366	6164	5968	92	183
20	5779	5596	5419	5247	5081	4920	4764	4613	74	142
21	4467	4325	4188	4055	3927	3802	3682	3565	55	109
22	3452	3342	3236	3134	3035	2939	2846	2756	42	85
23	2668	2583	2501	2422	2345	2271	2199	2129	33	65
24	2062	1996	1933	1872	1813	1755	1700	1646	25	51
25	1593	1543	1494	1447	1401	1356	1313	1272	20	39
26	1232	1193	1155	1118	1083	1049	1015		15	29
									12	24

REFERENCES

- ATOMIC ENERGY RESEARCH ESTABLISHMENT, HARWELL 1950: *Radioactive Materials and Stable Isotopes Catalogue No. 2*.
- BAYLY, J. G. 1950: A Calorimetric Measurement of the Disintegration Rate of a P^{32} Source. *Canad. J. Res. A28*: 520-9.
- CACCIAPUOTI, B. N. 1938: Determination of the Decay Constant of P^{32} . *Nuovo Cimento* 15: 213-9. (Cited by Bayly (1950), also in *Chem. Abs.* 32: 89225.)
- HENDRICKS, R. H.; BRYNER, L. C.; THOMAS, M. D.; IVIE, I. O. 1943: Measurement of the Activity of Radiosulphur in BaSO_4 . *J. phys. Chem.* 47: 469-73.
- HOLLANDER, J. M.; PERLMAN, I.; SEABORG, G. T. 1953: Tables of Isotopes. *Rev. mod. Phys.* 25: 469-651.
- KIRBY, H. W. 1954: Decay and Growth Tables for the Naturally Occurring Radioactive Series. *Analyt. Chem.* 26: 1063-71.
- KIRBY, H. W.; KRAMER, D. A. 1955: Simplified Procedure for Computing the Growth of Radioactive Decay Products. *Ibid.* 27: 278-9.
- KNAUSS, H. P. 1948: Slide Rule Calculations of Radioactive Decay. *Science* 107: 324.
- LIVINGOOD, J. J.; SEABORG, G. T. 1939: Radioactive Isotopes of Zinc. *Phys. Rev.* 55: 457-63.
- LYON, W. S. 1952: Disintegration of Cr^{51} . *Ibid.* 87: 1126.
- MATHEWS, D. E.; POOL, M. L. 1947: X-ray Emission from Radioactive Ce, Pd and Ca. *Ibid.* 72: 163-4.
- RABINOWICZ, E. 1950: A Photographic Method for Determining Half-lives. *Proc. phys. Soc. A63*: 1040-1.

- SAXON, D.; HELLER, R. 1949: The Gamma-rays Following Au^{198} β -Decay. *Phys. Rev.* 75: 909-10.
- SCHUMAN, R. P.; CAMILLI, A. 1951: Half-lives of Cu^{66} , Cu^{64} , Fe^{59} and Ce^{144} . *Ibid.* 84: 158-9.
- SIEGBAHM, K. 1947: The Disintegration of K^{42} . *Arkiv. Nat. Astron. Fysik.* B34(4), 7 pp.
- SILVER, L. M. 1951: Precision Measurement of Half-lives of Radioactive Substances. *Canad. J. Phys.* 29: 59-65.
- SREB, J. H. 1951a: The Half-life of Na^{24} . *Phys. Rev.* 81: 469.
- 1951b: The Half-life of I^{131} . *Ibid.* 81: 643.
- TOBAILEM, J. 1951: Mesure précise de la Période de quelques Radio-éléments. *C. R. Paris* 233: 1360-2.
- UNITED STATES BUREAU OF STANDARDS 1950: *Nuclear Data. Circular* 499.

CORRIGENDUM

Vol. 38, August 1957; McDowall *et al.*, Effects of Ingestion of Paraffins by Ruminants. II.

- p. 843, Fig. 2 (ordinate), Iodine value: *for* 225, 235 *read* 30, 40.
- p. 845, Fig. 6 (ordinate), Carotene in blood: *for* 100, 200 *read* 10, 20.
- p. 846, Fig. 8 (ordinate), Xanthophyll in blood: *for* ($\mu\text{g}/\text{ml}.$) *read* ($\mu\text{g}/100 \text{ ml}.$).

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